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16. ABSTRACT

Probable changes in the mix of materials used to manufacture automobiles were examined to determine if economic or technical problems in recycling could arise such that the "abandoned automobile problem" would be resurrected. Future trends in materials composition of the automobile were quantified, and possible constraints related to material characteristics, availability, and price were examined. The automobile resource recovery industry was studied in terms of economic incentives for recycling and technical obstacles to recycling of deregistered automobiles. A macro-model of the economy, the EPA sponsored SEAS model, was used to study overall economic and environmental effects and to bring to light any secondary effects that might be important.

This volume contains appendices covering the following subjects:

1) Future Material Composition in Automobiles
2) Projections of Automobile Sales by Weight Class
3) Automotive Use of Plastics and Recycling Possibilities
4) Safety Aspects of Materials Substitution
5) Energy Consequences.

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APPENDIX A

FUTURE MATERIAL COMPOSITION IN AUTOMOBILES

by Roy Renner

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A.1 INTRODUCTION

Automobiles are major consumers of materials resources. They also consume significant amounts of energy, not only in terms of direct consumption of fuel, but also in energies required for manufacturing activities, upkeep, and automotive-related facilities. Even the salvaging or recycling of worn out automobiles must be included in energy accountability. In addition, the automobile makes a heavy impact upon the environment.

Shortages of materials and energy resources, and degradations of the environment have forced an examination of the automobile's role in American life. Over the past decade, much has already been done to reduce exhaust emissions -- and much still remains to be accomplished. We are beginning to see the accelerated development of alternative modes of transportation, particularly for urban areas. And just in the last few months, the American Public has come to realize that energy conservation must become an on-going part of daily life.

The participants in this study (many of whom have been professional observers of the automotive scene for several years) believe that the private passenger car is here to stay. Automobiles are too useful and too pleasurable to be replaced in the foreseeable future. Social values are beginning to shift perceptibly, however, in recognition of some of the automobile's more adverse impacts. Auto manufacturers are in turn responding to these new values and concerns, in response to the dual pressures of legislation and buyer preferences.

The result will be that at least over the next 25 years, the American automobile will change in many basic ways. A new era in automotive engineering is foreseen, in which engineering toward functionalism and conservation will dominate.

The prospect that the vehicle will change in basic ways -- and there are many choices and alternatives available to the designer -- greatly complicates any detailed forecast. And yet, certain trends are becoming clear.

Smaller and lighter cars appear probable because they consume less fuel and materials resources, and cause correspondingly less pollution. Moreover, smaller vehicles use less street and storage space, causing less congestion. It is reasonable to expect that they would cost less to purchase and maintain.

Some potential conflict may exist, inasmuch as safety requirements may be easier to meet in larger, heavier cars. Doubtless the technical challenge to produce safer small cars can be satisfactorily met in the future, particularly when it is observed that the mix of traffic will contain higher percentages of smaller vehicles.

Many cars will still be needed with passenger accommodations large enough for family transportation. It has been shown that external dimensions can be significantly reduced, without sacrificing passenger space. Furthermore, fuel consumption can be greatly reduced by reducing vehicle weight and by improvements to engines and power trains and with better tires and aerodynamics.

As one example of weight reduction, it has been estimated that within a few years a car now weighing 3600 lb could be built to weigh 2925 lb with no reduction in passenger compartment size. This could be done by substituting 305 lb of aluminum parts for 755 lb of steel parts, and reducing the weight of other load-carrying components by a total of 225 lb (1).*

There is a reasonable certainty that future weight reductions will be accomplished, in large measure, by the substitution of lighter materials for steel. The steel requirements for auto construction may decline by as much as 50% between 1974 and 1995 (2). The most likely substitutes appear to be aluminum and plastics. The difficult part of the forecast (and of vital concern in the question of recycling of materials) is determining the relative amounts of aluminum** and plastics that will actually come into use. As we shall see later on in this study, a several-fold increase in the use of either or both of these materials is likely to come to pass. The factor by which these materials enter into auto manufacturing may increase by two to five times the present amounts per vehicle.

The criteria to be considered by future designers in materials selection will be numerous and complex. Structural adequacy and physical properties will remain important, but so will many other considerations such as manufacturability, resource availability, energy implications, recycling, safety, environmental impact, and economic factors. The economics will, of course, be strongly interrelated with the other factors. The very act of forecasting the relative weighting of the various criteria will, of course, partially determine the choices of plastics vs. aluminum.

---

* Numbers in parentheses designate references listed at the end of this report.

**The word "aluminum" will be used in this report to mean "aluminum alloys." Pure aluminum is seldom, if ever, used as a structural material.

Inasmuch as this study relates mainly to recycling considerations, the principal emphasis will be attached to those materials which are likely to constitute the largest tonnages in future manufacture. Furthermore, the most detailed examination will be given those materials which will undergo the greatest change in usage. The use of rubber in autos will remain important, for instance, but the relative amount will probably not change appreciably. Important trade-offs will probably be among the steels, the plastics, and aluminum.

Over the next decade (1975-85), most of the materials changes will reflect substitutions rather than radical design changes. In the following decade of 1985-95, there may well be some fairly substantial changes in basic design philosophy -- such as new propulsion systems. The familiar internal combustion engine may yield to such alternatives as the gas turbine, Rankine or Stirling cycle engines, or perhaps even hybrid powerplants. There may well be an increase in the use of electric vehicles for specialized applications, but the total numbers of these is not likely to become large until or unless some fundamental breakthroughs in battery technology become available. In the "post-fossil-fuel-era" (almost certainly beyond the year 2000), practical energy-storage vehicles powered by batteries or flywheels may become prominent.

This present study will necessarily involve a number of superimposed assumptions and projections. The results and conclusions, therefore, cannot be regarded as precision forecasts but rather will be expressed as a range of possibilities. We will endeavor to portray a "maximum plastics auto," a "maximum aluminum auto," and also the more likely composition based upon a less-radical departure from current practice. Ingredients in the study will be estimates of numbers of vehicles that may be manufactured in each of three weight classes, recognizing that car weights within each class will decline.

The materials composition of present day cars will be identified from other recent studies. Projections of percentage composition will be projected into the future on an assumed evolutionary basis. The baseline 1975 auto composition will be regarded as somewhat arbitrary, since this composition is accurately known only for a few makes and models.

It is important to recognize the time lag between the introduction of a new model and its ultimate scrapping. Thus, a new 1980 automobile will become statistically important in recycling activities sometime in the post 1990 time frame. By the same token, our projection of the 1985 recycling activities will involve the "safe" knowledge of what this year's new model cars are made.

Aftermarket implications (replacement parts) also could be an important consideration. Furthermore, there always will be some internal circulation of materials in the form of used auto parts or reconditioned subassemblies. We will attempt to evaluate the relative importance of such activities.

A.2. HISTORICAL TRENDS

A.2.1 Alternative Materials of the Past

The subject of alternative materials in automotive manufacture is as old as the motor car itself. The apparent reasons for materials substitution have changed through the years.

A number of early automobiles -- mainly those in limited production -- had aluminum bodies. The ease of forming the relatively soft, ductile material by hand methods appeared to be the main consideration, rather than weight reduction. High-strength, hardened aluminum alloys had not yet come into widespread commercial use. The main function served was a covering material over a body framework. Often, the body framing was of wood. Early auto ads referring to aluminum bodies include those for the 1917 Stanley steam touring car (3) and the 1920 Haynes (4).

Cast and wrought aluminum also were widely used for engine and drive train components. The 1906 Model "S" Oldsmobile had an aluminum engine crankcase (5), while the Overland of 1912 had a crankcase and gear cases from this material (6). Even aluminum alloy engine blocks date back many years, among the first being a V-16 engine produced by Marmon in 1931 (7).

Significant portions of automobiles formerly were made from wood, fabric, and leather. These components included wheel spokes, body framing and coverings, upholstery, and tops. Such materials were common until the early 1930's. All-steel "turret tops" did not appear on General Motors cars until the 1935 model. One-piece steel tops were made possible with advancements in the manufacture of wide steel sheets, together with the introduction of enormous presses (8).

Copper, bronze, and brass were, at one time, in more prominent use than today. These easily workable materials, which also have many other desirable properties such as corrosion resistance and excellent thermal and electrical conductivity, were displaced by other materials as prices rose.

Even some of the early plastics enjoyed limited use: celluloid windows in side-curtains, hard rubber steering wheels, "Bakelite" in electrical devices, and phenolic laminate timing gears are some random examples.

The extensive use of aluminum and plastics for weight reduction first became popular in trucks, rather than in passenger cars. While some of this pioneering work began much earlier, long-distance truck operators began to find tangible economic advantages in lightweight materials immediately after World War II. Trucks began to appear with aluminum frames, bodies, wheels, cabs, bumpers, transmission cases, and fuel tanks. A rule-of-thumb of the 1950's was that a one dollar premium in purchase price was worth while for each pound of weight saved for line-haul applications on the Pacific Coast.

More recently, a considerable body of experience has been gained in the use of fiber glass truck components. A noteworthy example is the one-piece hood and front fenders of Kenworth trucks. Another example is the use of fiberglass front fenders by Peterbilt Motors of Newark, California.

Plastics and aluminum have not as yet found extensive use in the bodies of modern automobiles. Exceptions are found in the case of some specialty cars, such as the fiberglass body of the Chevrolet Corvette.

A.2.2. Significant Trends

Much has been said, recently, about the noticeable trends in cars becoming steadily heavier, and in steadily decreasing fuel mileage. Emission control equipment and recent safety requirements often have been blamed for these trends, but a review of the facts shows that these trends existed even before the advent of such regulated design features. Figure A1 for example, shows that the curb weight of "standard size" cars has generally increased over many years. Figure A2 shows a corresponding decrease in fuel economy over a similar period.

Much of the tendency toward heavier cars and concomitant higher fuel consumption can probably be attributed to the steadily rising affluence in America over the past thirty years. The domestic auto industry found a commercial advantage in promoting the large car as a visible symbol of status and well-being. Power accessories and air conditioning have become regarded as necessities rather than luxury items. Even low priced cars tended to become larger year by year.

Reference (12) gives the results of a study by the U.S. EPA on the contributing causes of deteriorating fuel economy.

These factors were found responsible for increased fuel consumption over recent years:

- Increased car weights.
- More cars being equipped with power accessories and air conditioning.
- Emission controls.
- More cars being equipped with automatic transmissions.

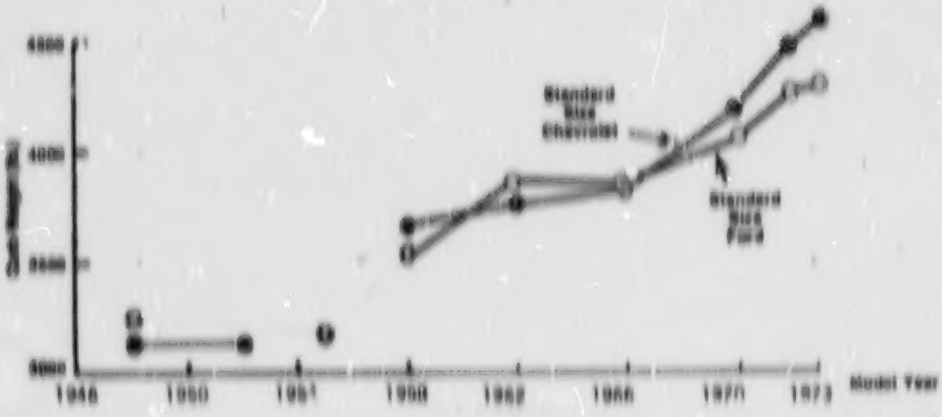


Fig. A1 Curb Weight of Standard Size Cars vs. Model Year (From References 9, 10, 47, 48)

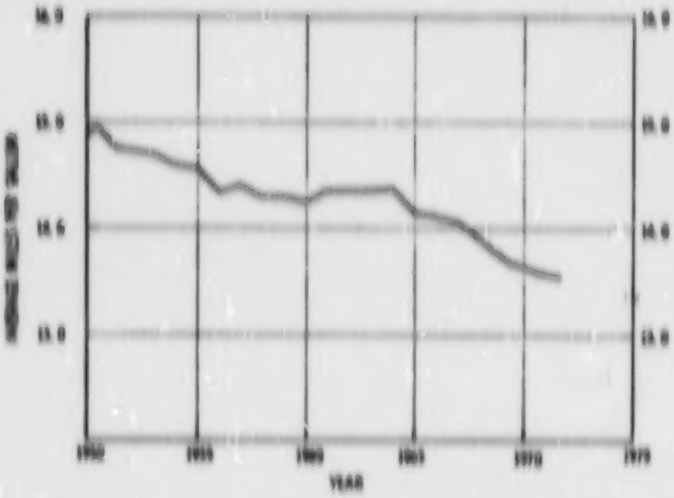


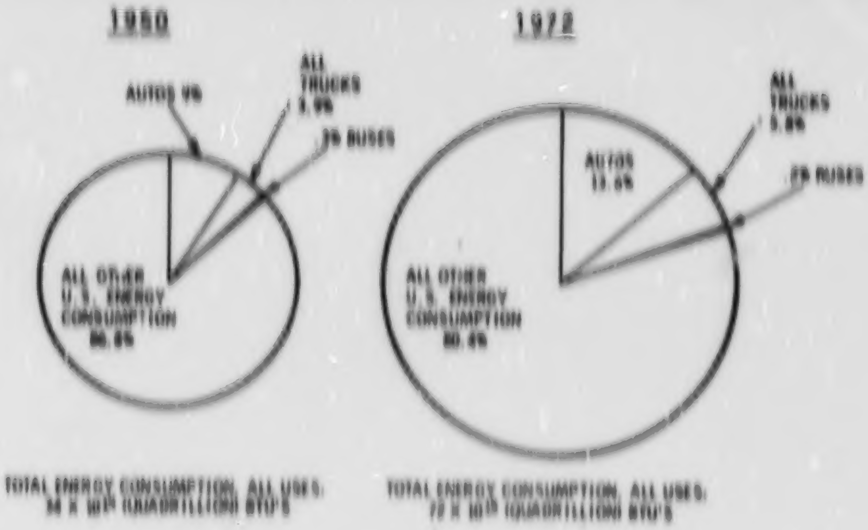
Fig. A2 Trends in Passenger Car Fuel Economy, Composite of U.S. Car Fleet (From Ref. 11).

How much energy is being consumed by motor vehicles in the U.S.? Figure A3 compares the energy consumption in 1972 with that of the year 1950. In 1950, fuel for autos accounted for 9 percent of the total U.S. consumption of 34 x 10^{15} BTU. By 1972, fuel energy supplied to autos was more than triple the 1950 value -- being nearly 14% of a much larger total consumption of 72 x 10^{15} BTU (11). A better perspective is gained by considering these additional statistics:

1. In Fig. A3, the fraction of energy associated with autos was the fuel energy only. In our study, we will need to consider the total energy devoted to the motor car, including the energy used to manufacture the vehicle. Table A1 indicates that the energy devoted to automobiles is about 21% of the total U.S. energy consumption. Direct fuel consumption accounts for about 58% of the total energy requirement for automobiles. The combined activities of auto manufacturing, tire manufacturing and sales, together with aftermarket parts and repairs are nearly 10% of the total energy requirement for automobiles.

2. While fuel for autos is around 14% of the total U.S. energy consumption, the automobile is the largest single user of petroleum. Passenger cars account for about 30% of annual U.S. petroleum usage.

Conservation of energy, with emphasis on reducing dependence upon petroleum, has become a national goal of high priority. Significantly, the Federal government has recently announced a goal of improving fuel mileage by 40% between now and the year 1980 (15). A number of approaches has been suggested in order to obtain more miles per gallon of fuel. Some



Sources: (1) U.S. Bureau of Mines, Minerals Yearbook
(2) FHWA Highway Statistics, 1972

Fig.A3. Fraction of U.S. Energy Consumed by Automobiles in 1960 and 1972 (From Reference 11)

TABLE A;

TOTAL ENERGY REQUIREMENTS FOR AUTOMOBILES IN THE UNITED STATES
(From Reference 13)

Note: All energy figures are in units of 10^{15} BTU

	1960	1970
Gasoline consumption	5.60	8.94
Gasoline refining and retail sales	1.28	2.07
Oil consumption, refining, retail sales	0.07	0.11
Automobile manufacturing	0.86	0.80
Automobile retail sales	0.17	0.21
Repairs, maintenance, parts	0.36	0.37
Parking, garaging	0.22	0.44
Tire manufacturing and retail sales	0.09	0.23
Insurance	0.19	0.31
Taxes (highway construction)	0.73	1.00
Total (10^{15}BTU)	9.56	14.48
Total United States energy consumption (10^{15} BTU)	44.57	67.44
Percent of total energy consumption devoted to automobiles	21%	21%
On a Mileage Basis:		
Total automobile mileage (10^9 miles)	590	901
Total energy required (BTU/mile)	16,200	16,100

generalized strategies include:

- Reductions in the size and weight of the vehicle.
- Improvements in vehicle design to reduce rolling resistance and air drag, such as better tires and improved streamlining.
- The development of more efficient transmissions and power trains.
- Improvements in the thermal efficiency of the engine.

The automobile manufacturers are already making firm plans to reduce car size and weight. Therefore, we can safely predict a sharp downturn in the trends of car weight. A major thrust of this study will be to forecast the decline of car weights, and the impacts of materials substitutions which will be involved in weight reduction. If a substantial amount of substitution with lighter materials will occur over the model years 1976-1981, the impact of these new materials upon recycling activities will be felt about 10 calendar years later, or 1986-1990.

Reductions in rolling resistance and air drag will have some impact upon the materials situation (tire materials and covered chassis components) but this impact will be less than the factor of weight reduction discussed above.

Improvements to the transmissions and power trains would not greatly influence the materials used for these components, unless some radically new type of transmission is developed. Most manufacturers are contemplating rather simple modifications to the transmission, such as a torque converter lockup feature.

Improvements in engine thermal efficiency will have but a minor effect upon materials used for the time being. However, if the time comes when the ICE is replaced by a quite different powerplant (gas turbine, Rankine or Stirling engines), there will be a significant change in the materials outlook. If such new powerplants are introduced over the period 1985-1990, the problem of initial supply will occur during those years, with the impact upon recycling taking place in the period 1995-2000 and beyond.

Figure A4 is indicative of the technological potential for fuel economy improvement over the next 10 years. We have suggested that weight trimming activities will come early in this period.

It is perhaps obvious that the largest cars also have the greatest potential for weight reduction. This will occur both by reducing the outside dimensions of the vehicle (which does not necessarily reduce passenger room) and by the use of lighter materials. If the lowest curve in Fig. A4 is selected for examination, it will be seen that reducing the inertia weight* from 5,000 lb to 4,000 lb would increase the fuel economy from about 10.6 mpg to around 12.7 mpg. This is almost a 20% improvement.

As another example, reducing a compact car's weight from 3,500 lb to 3,000 lb. would result in a 30% improvement in mileage -- from 15 mpg to 19.5 mpg.

One must recognize the importance of distinguishing between the concepts of fuel economy (say in mpg) and fuel consumption (say in gallons per 100 miles

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*The term "inertia weight" refers to the weight used for test purposes. Usually, it is the curb weight of the vehicle with the fuel tank at least half-full, plus 300 lb to simulate a nominal passenger load.

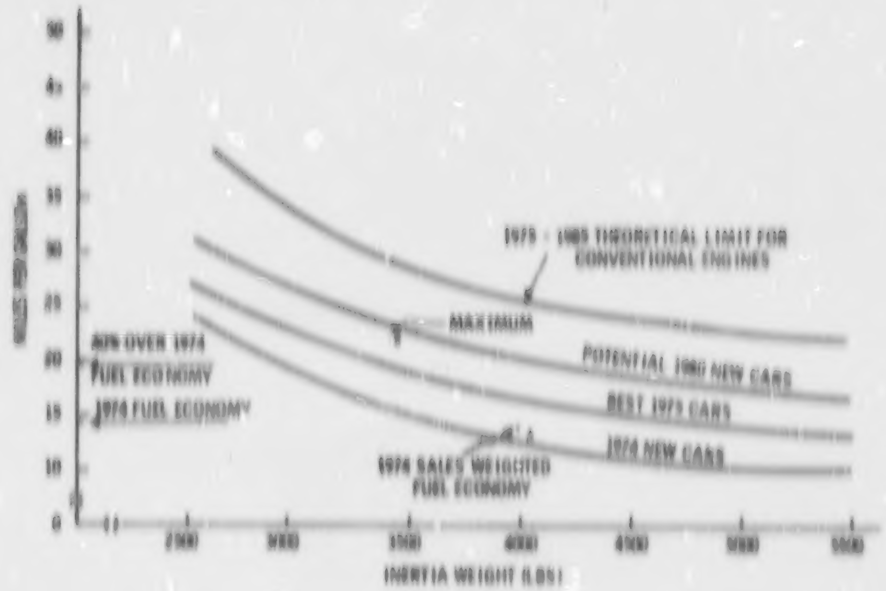

Fig. A4 Technological Potential for Fuel Economy Improvement. (From Ref. 11)

of travel). In the first of the two examples given above, gasoline consumption would be reduced from 9.43 gal/100 mi to 7.87 gal/100 mi or a 16.5% reduction. In the second example, fuel consumed would be reduced from 6.67 to 5.13 gal/100 mi, a reduction of 23%. However, in both cases the amount of fuel saved is about the same: a little over 1-1/2 gallons saved per 100 miles of travel.

An important factor in our study is the time lag between the introduction of a new model, and the time when cars of that model year are expected to be scrapped and materials reclaimed.

Table A2 indicates a significant trend toward increased longevity of cars between the years 1925 and 1954. The average age of cars scrapped in 1925 was said to be only 6.5 years, after the vehicle had been driven 25,750 miles. These figures had risen to 13.8 years and 122,000 miles by 1953, after which some decrease was noted. While some questions might be raised about data portraying average mileages much over 100,000 miles, yet it was clear from common experience over those years that the serviceability of cars had steadily increased. Part of the increase shown from 1941 to the early 50's can be attributed to the World War II emergency and to the years following, when new cars were hard to get. A vehicle can be kept running almost indefinitely if need be, so long as replacement parts remain available.

Additional durability data over subsequent years is given in Table A3. Inspection of these data would seem to indicate that the extrapolated "average" age of the later model autos appears to be around 10 years. Assuming 10,000 mi/yr to be typical for those years, the mileage at the time of scrapping

TABLE XI

AVERAGE AGE AND MILEAGE OF CARS WHEN SCRAPPED

(From Reference 14, Derived from
"Automotive Facts and Figures," 1955.)

	1925	1930	1935	1941	1950	1953	1954
Age, yrs	6.5	7.0	8.3	10.2	13.5	13.8	13.2
Mileage driven	25,750	41,500	58,000	85,000	116,500	127,265	115,000
Annual mileage	4,720	5,900	7,000	8,330	8,630	8,830	8,710

TABLE A3

NUMBER OF CARS, AS A PERCENTAGE OF THEIR ORIGINAL REGISTRATION, STILL IN SERVICE AS OF JULY 1 OF THE YEAR LISTED

(From Reference 16, Compiled from R. L. Polk Figures, *Automotive Industries*, Various Annual Statistical Issues.)

	Seven Years Old		Eight Years Old		Nine Years Old	
Year	All[a]	Big Three Only[b]	All[a]	Big Three Only[b]	All[a]	Big Three Only[b]
1953	92.86	91.80	----	----	----	----
1954	91.81	91.96	88.09	89.74	----	----
1955	92.84	93.06	85.40	86.16	79.07	80.70
195	87.52	90.10	83.61	84.74	71.26	72.34
1957	89.34	90.16	78.35	79.55	68.73	70.93
1958	86.57	87.64	79.33	80.76	64.37	65.89
1959	88.58	89.40	79.64	81.17	69.55	71.49
1960	89.29	89.83	79.00	80.49	67.06	69.17
1961	89.48	89.86	80.23	81.21	68.56	68.41
1962	90.27	90.42	81.58	82.26	68.91	70.27
1963	88.64	88.91	81.73	82.08	71.95	70.84
1964	85.31	85.60	78.81	79.18	71.09	70.59
1965	87.01	86.13	75.24	75.79	66.78	67.20
1966	86.23	86.48	72.89	71.51	60.19	60.83
1967	87.47	86.36	73.84	74.34	56.12	55.23

(a) For reasons of consistency, Imports, Willys, and Kaiser-Frazer vehicles subtracted from the R. L. Polk totals.

(b) Excludes De Soto and Edsel.

was around 100,000 miles. The data further hint that younger cars were being scrapped in the late 60's compared to previous decade. If so, either cars decreased in durability, or else their owners found a decreasing incentive to keep their older cars maintained.

A.3 MATERIALS COMPOSITION OF MODERN AUTOMOBILES

A.3.1. Baseline Car Classifications

As a first step in the study of materials which compose current model automobiles, cars were classified according to three broad and somewhat arbitrary categories. This has been done partly because the percentages of each material differ somewhat among these categories, and also because the prospects for weight reduction differ. Moreover, it is possible to contemplate changes in consumer choice among these categories, and to consider differences in engineering problems such as compliance with safety regulations.

The three categories are:

- Class "A" - Full-size family cars, six passenger.
- Class "B" - Compact cars, five adult passengers.
- Class "C" - Small or subcompact cars, four adult passengers.

While the divisions represent the normal capacity in seated adult passengers, it generally follows that other features such as curb weight and engine size are characteristically similar within each category. Table A4 gives some of the characteristics that distinguish each car class.

It is acknowledged that there could be many other ways to classify private cars. The descriptors "luxury car," "sports car," "specialty vehicle," "intermediate sedan," "station wagon," "mini-car," etc., are useful but most of these types can be fitted into one of the three arbitrary classes, at least insofar as materials composition is concerned.

TABLE A4

BASELINE CAR DEFINITIONS (MODEL YEAR 1975)

Description	Car "A" Full Size Family Sedan	Car "B" Compact	Car "C" Small or Sub-Compact
No. Adult Passengers	6	5	4
Curb Weight, lb	>3,500	2,500-3,500	<2,500
Wheelbase, in	>110	98-110	<98
Total Length, in	>200	180-200	<180
Total Seating Width, in	>100	90-100	75-80
Luggage Space, ft^3	12-20	10-14	6-10
Engines:			
Typical No. Cyl.	8	6	4
Displacement, in^3	>300	200-300	<150
SAE Net HP	>140	95-120	<95
Fuel Economy, mpg*			
Urban	10-13	13-18	18-24
Highway	15-18	18-24	24-30

*By U.S. EPA dynamometer method. See Ref. (17).

Later in this study, we will make use of an average baseline vehicle weight for each of the three car classes. We have computed the approximate average weight of cars in each class, making use of published statistics of the number of cars manufactured of each make and model, together with shipping weights. The shipping weights of 1975 model cars are published in the Kelley Auto Bluebook (23). Statistics on U.S. car production, by make and model for the 1973 model year, are given in the 1974 issue of Ward's Automotive Yearbook (22). This same reference gives statistics on cars imported into the U.S. Table A5 is a summary of the calculations of the baseline car weights that will be assumed for 1975 model cars. These "average" weights should be regarded as typical for each class. Due to the fact that weights of cars of a given model vary somewhat according to optional features installed, it is not possible to state these averages with great accuracy, nor is this required for our purpose.

A.3.2 Materials Composition of Autos: Recent Studies

While it may not be possible to develop precise data on the materials composition of the "average" or "typical" 1975 model automobile, a number of recent studies do reveal the approximate weights of certain broad materials classes which make up some recent model cars. From the literature describing these studies, we will formulate an approximate "baseline" materials composition of each car class.

Dean and Sterner, of the U.S. Bureau of Mines, described such an investigation in a report issued in late 1969 (18). The purpose of the investigation was to study the economics of recovering scrap materials from junk automobiles. Fifteen automobiles, manufactured between 1934 and 1965, were dismantled and analyzed. From this, the materials composition of

TABLE A5

SUMMARY OF CALCULATIONS, DETERMINATION OF AVERAGE BASELINE WEIGHT[a] OF AUTOMOBILES IN EACH CLASS

Car Class	Number of Car Models Included in Average	Average Shipping Weights,[a] lb	Less Fluids,[b] lb	Baseline: Average Dry Weight of Materials, lb[c]
A (Full Size)	36	4401	65	4340
B (Compact)	19	3053	55	3000
C (Small)	17	2218	38	2180

(a) Sales-weighted average, using 1975 model shipping weights and 1973 model sales statistics.

(b) Fluids in cars as shipped include engine and gear oil, water, brake fluid, but little if any gasoline. Automatic transmission assumed for "A" and "B", and manual transmission for "C."

(c) Rounded off to nearest ten pounds.

a "representative" junk automobile was determined. Summarized findings are given in the first two columns of Table A6 and compared with the results of other studies. The composite auto described by the USBM was said to be typical of a "ten-year-old, four-door sedan, in the low-price class, with automatic transmission, radio, and heater, and of modified unitized body design (18) Ten years old in 1969 would indicate a composite describing a 1959-era automobile. A number of differences would exist in today's cars, 16 model years later. And yet, the results of the USBM study are a useful check in our work, since it represents one of the most extensive analyses ever done on this subject.

Much more recent data were developed by the marketing group of the Armco Steel Corporation (21). These data, obtained by dismantling a single 1972 automobile, are also given in Table A6. The automobile was described as a 1972 standard size two-door model, equipped with a V-8 engine, automatic transmission, power steering, power disc brakes, radio, and air conditioning. A car thus described would fit within our "category A" automobile. It is interesting to note that the weight composition included 61.4% steel and steel alloys, 17.1% cast iron, 4.6% plastics, and 2.6% aluminum. Of further interest is the very high plastics content, when compared to other cars described by Table A6. While methods of accounting may have differed among the several studies, it is intriguing that the relative amounts of rubber vs. plastics appear to have traded places when the Armco results are compared with the earlier studies. The Armco listing for cast iron is also somewhat higher than shown for the others.

TABLE A6

MATERIALS COMPOSITION OF RECENT U.S. AUTOMOBILES

	[illegible] Composite 1959-1965		Dodge Dart 1965		Plymouth Belvedere 1965		Chrysler New Yorker 1967		1969 [illegible] Composite		1972 Two-dr. Sedan	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	–	–	1616	61.2	1956	61.7	2492	58.9	–	–	2175	52.2
Alloy & Stainless Steel	–	–	120	4.5	126	4.0	204	4.7	–	–	380	9.2
Total Steel	2532	70.8	1736	65.7	2082	65.7	2696	63.7	2302	62.2	2555	61.4
Cast Iron, Malleable Iron	511	14.3	402	15.2	455	14.4	605	14.3	528	14.3	712	17.1
Aluminum	51	1.4	33	1.2	77	2.4	72	1.7	55	1.5	108	2.6
Copper, Brass	32	0.9	28	1.1	36	1.1	44	1.0	30	0.8	56	1.4
Rubber	145	4.1	147	5.6	171	5.4	189	4.5	96	2.6	120	2.3
Glass	87	2.4	74	2.8	96	3.0	124	2.9	–	–	108	2.6
Plastic	–	–	16	0.6	18	0.6	33	0.8	54	1.5	190	4.6
Other	216	6.0	205	7.8	230	7.3	469	11.1	645	17.4	320	7.7
Totals[a]	3575	99.6	2641	100.0	3165	99.9	4231	100.0	3700	100.0	4163	100.1
Reference No.	(18)		(2,19)		(2,19)		(2,19)		(2,20)		(21)	

(a) Total weights should represent dry curb weight. For actual curb weights with water, oil, and one-half tank fuel, add approximately 130 lb. Percentages may not total 100% in all instances due to numerical round-offs.

Additional data on materials composition is given in Table A7, as found in Ward's Automotive Yearbook for 1974 (22). This table is interesting because of the more detailed breakdown. It also shows a late model Plymouth car (1973) compared with earlier models in a uniform reporting format.

Table A7 confirms that cars have been getting heavier, that steel accounts for approximately 60% of a car's weight while cast and malleable irons are about 15%. The use of plastics rose sharply from 10-20 lb per car through 1968, to well over 100 lb. per car in 1973. The aluminum content for these Plymouth cars stayed about the same, about 75 lb per car.

A.3.3. Materials Usage by Component or Function

Table A8 gives another perspective on materials usage in automobiles. The "upper body group"--mostly steel and glass--is the largest of the weight categories listed, with "power plant"--mostly cast iron--being a strong second.

Table A9 gives several examples of the applications of various automotive materials by component. This table is intended to be illustrative only, and many other example components could be cited. Some components, such as "grilles and trim," are listed under several materials categories as being alternatives observed in current model automobiles.

The term "plastics" does not completely define the material being used. Table A10 identifies some of the specific families of plastics with examples of their use. Not all of the listed plastic parts are used on all cars, of course. Table A11 gives additional information of the approximate weights of the various plastics typically used in 1974 passenger cars. Two estimates

TABLE A7

MATERIALS COMPOSITION OF RECENT MODEL PLYMOUTH AUTOMOBILES

(Source: Reference 22)

	1973	1968	1963
Wheelbase, in	120	116	116
Standard Engine	V-8(318-cu.in.)	V-8(3[illegible]-cu.in.)	V-8(273-cu.in.)
Transmission	Automatic	Automatic	Automatic
Steering	Power	Manual	Manual
Brakes	Power	Manual	Manual
Heater	Yes	Yes	Yes
Radio	Yes	Yes	Yes
Curb Weight, lb	4014	3415	3355

Material Grouping in Lbs. and Percent

	1973 Wt.,lb	1973 Wt.%	1968 Wt.,lb	1968 Wt.%	1963 Wt.,lb	1963 Wt.%
Cast Iron	482	12.0	394	11.5	473	14.0
Malleable Iron	169	4.2	64	1.9	63	1.9
Plain Carbon Steel	2105	52.4	1914	56.0	1807	53.9
Galvanized Steel	75	1.9	71	2.1	53	1.6
Aluminized Steel	31	0.8	24	0.7	24	0.7
Alloy Steel	95	2.4	121	3.5	121	3.6
Stainless Steel	13	0.3	12	0.4	12	0.4
Aluminum	75	1.9	71	2.1	75	2.2
Magnesium	0	0.0	0	0.0	2	0.1
Zinc	65	1.6	37	1.1	28	0.8
Copper and Copper Base Alloys	26	0.6	38	1.1	36	1.1
Lead	22	0.5	30	0.9	32	1.0
Body Solder	5	0.1	5	0.1	5	0.1
Glass	96	2.4	90	2.6	82	2.4
Rubber	201	5.0	173	5.1	174	5.2
Plastics	125	3.1	21	0.6	12	0.4
Soft Trim, Paper, Cardboard & Components	110	2.7	92	2.7	85	2.5
Sound Deadeners and Sealers	77	1.9	47	1.4	56	1.7
Paint and Protective Dip	26	0.6	20	0.6	17	0.5
Fluids and Lubricants	216	5.4	191	5.6	198	5.9
TOTALS	4014	99.8	3415	100.0	3355	100.0

TABLE A8

Weight Breakdown for Chrysler Corporation Cars

According to Component or Function

1972 Vehicles with 1973 Bumper Systems
(From Reference 24)

Weight Component Group	Valiant lb	Vehicle Weights Satellite lb	Fury lb	Newport lb
Chassis Groups				
Power plant	641	644	710	848
Final drive	116	170	180	173
Forestructure	103	138	171	171
Suspension	156	179	234	244
Steering	46	47	75	75
Brakes	107	152	186	188
Wheels & tires	166	193	222	256
Exhaust	28	36	42	55
Fuel system	22	31	31	31
Bumpers	108	131	169	171
Body groups				
Lower body	194	225	302	320
Upper body	999	1211	1334	1476
Total vehicle wt.	2918	3404	3957	4280

TABLE A9, PART 1

EXAMPLES OF MATERIALS USED FOR VARIOUS AUTOMOBILE COMPONENTS

(1970-1975 MODEL CARS)

Steels				
Low Carbon, Low-Alloy	Alloy Steel	Stainless Steel	Cast Iron, Malleable Iron	Aluminum Alloys
Chassis frame	Springs	Grilles	Engine block	Engine block
Suspension parts	Gears	Trim	Cylinder heads	Cylinder heads
Body, hood	Bumper brackets	Hub caps	Crankshaft	Intake manifold
Axle housing	Connecting rods	Wiper arms	Camshaft	Clutch, transmission housing
Propeller shaft	Piston pins	Catalytic converters	Clutch, transmission housing	Pistons
Bumpers	Valves	Thermal reactors	Exhaust manifolds	Grilles
Wheels	Magnets	Heat risers	Brake drums	Trim
Fuel tank	Bearings	Bolts, fasteners	Brake disks	Bearings
Clutch parts	Shafts		Steering gear case	Bumpers
Painted or plated grilles, trim	Axles		Brake cylinders	Wiring
Brackets	Seat springs		Oil pump	Wheels
Exhaust system	Tire cords		Water pump	Brake pistons
Starter, alternator frames	Bolts, fasteners		Intake manifold	Battery cables
Fan			Piston rings	Aluminized steel
Pulleys			Clutch parts	Radiator
Linkages			Cylinder lines	Air conditioning components
Window mechanisms				Window frames
Crankshaft				
Armature, electromagnet cores				
Brake shoes, backing plates				
Tubing				
Bolts, fasteners				

TABLE A9, PART 2

EXAMPLES OF MATERIALS USED FOR VARIOUS AUTOMOBILE COMPONENTS

(1970-1975 MODEL CARS)

Copper, Copper Alloys	Zinc	Lead, Tin	Plastics	Rubber
Radiator	Grilles	Battery	Grilles	Tires
Heater core	Trim	Radiator solder	Trim	Engine mounts
Starter, alternator windings	Carburetor	Body solder	Battery case	Transmission mounts
Wiring	Fuel pump	Electrical solder	Wiring insulation	Door seals
Tubing	Lamp housings	Terne plating, fuel tank	Fender apron	Wiring insulation
Tube fittings	Galvanizing coatings	Bearings	Fan shroud	Power brake diaphragm
Gaskets	Handles	Battery cable terminals	Fan blades	Brake seals
Elec. motors	Knobs		Ducts	Engine tubing
Contacts			Fan housing	Body mounts
Electronics			Lenses, lamp	Radiator hose
Bearings			Lamp housings	Heater hose
Bushings			Bumper sight shield	Pedals
Air cond. condensers			Bodies, sport cars	Window gaskets
Instruments			Crash pad	Drive belts
			Headrest	Gaskets
			Upholstery	
			Small gears	
			Bushings	
			Tubing	
			Safety glass	
			Tire cords	
			Instruments	
			Gaskets	
			Insulation	
			Ignition parts	
			Steering wheel	

TABLE A10

USES OF PLASTICS IN 1974 AUTOS

(Sources: References 25,26,27)

Applications	Plastics	Pounds per Car
INTERIOR		
Crash pad	Urethane, ABS, PVC	6
Headrest pad	Urethane, PVC	3
Trim, glove box	Polypropylene, PVC, ABS	16
Seat (soft)	Urethane	20
Seat belts	Nylon	3
Upholstery, carpet	PVC, nylon	16
EXTERIOR		
Fender apron	Polypropylene, polyethylene	14
Front end	Unsaturated polyester	15
Wheel covers	ABS, polyphenylene oxide	8
Fender extensions	Unsaturated polyester, nylon	3
Grille	ABS	3
Lamp housing (rear)	Polypropylene	3
Styled roof	PVC	6
Bumper sight shield	Ethylene-propylene copolymer, urethane	10
UNDER THE HOOD		
Ducts	Polypropylene	3
Battery case	Polypropylene	2
Fan shroud	Polypropylene	3
Heater and air conditioner housing	Unsaturated polyester	8
Electrical and wiring	Phenolic, PVC, polyethylene	10

Note: ABS=acrylonitrile-butadiene-styrene; PVC=polyvinyl chloride.

TABLE A11

PLASTICS USED IN 1974 PASSENGER CARS

(Two estimates, according to References 26,27)

Material	Usage, lb per Car Estimate by Garlund (26)	 Estimate by Heinold (27)
Acrylonitrile-butadiene-styrene (ABS)	15	16
Polyester (Glass reinforced)	10	17
Polyamide (Nylon)	6	3.8
Polyethylene	6	5.2
Acetyl, Polyacetyl	2	1.5
Acrylic	3	3.7
Phenolic	5	6
Polypropylene	22	23
Polystyrene	2	-
Poly Vinyl Chloride (PVC)	30	-
Polyurethane	35	-
Styrene-acrylonitrile (SAN)	1	1.2
Other (Cellulostics, Alkyds, epoxies, Polycarbonates, etc.)	12	8.1
TOTALS	149 lb.	85.5 lb.

in the table give 149 and 86 lb. of plastic materials per 1974 car, respectively. Other sources quote 138 lb plastics for 1973 model cars (28), 100 lb. for 1970 models (29), and 150 lb for 1974-model 6-passenger U.S. sedans (car "A") (2). Tables A6 and A7 already listed 129-190 lb per car for 1972-1973 model full-size cars. Therefore, it is probably reasonable to assume that a 1975 model six-passenger car "A" contains around 150 lb. plastics.

A.3.4. Baseline Materials Weights: 1975 Model Cars

The baseline dry weights of automobiles in classes A, B, C were computed earlier (Table A5) to be approximately 4340, 3000, and 2180 lb respectively. What are the 1975 baseline weights to be allocated for each materials class? Realistic estimates are possible for full-sized cars "A" based on the preceding tables. And noting that compact cars "B" are typically U.S. produced and are usually of conventional construction, it can reasonably be assumed that the percentages of each material are very similar to class "A" cars.

Small cars "C" are more often of somewhat different construction, have many national design origins, and embody a larger fraction of light materials. They usually are not simply scaled-down versions of larger cars. One reason the designs differ is the need to efficiently arrange the passenger and payload space. Often this calls for locating the entire powerplant and drive train at one end of the car or the other -- front engine/front drive or rear engine/rear drive. The weight of these parts must be minimized to preserve a reasonable and safe weight distribution for the vehicle. Aluminum alloy (and sometimes magnesium alloy) components are frequently employed. Other fundamental engineering differences include four-wheel, independent suspension with a minimum of unsprung weight and unit construction of the body and chassis.

The Chevrolet Vega may be taken as an example of a U.S.-produced car with a high percentage of aluminum in its construction. Many imported cars appear have a higher percentage of light alloys, while other domestic makes (Pinto, Gremlin) and imported models may have somewhat less. The Vega aluminum engine block weighs 36 lb (30). Other aluminum engine parts include pistons, oil pump and engine front cover, intake manifold, clutch housing, and air pump, adding 20-25 lb. Front and rear bumpers for the 1975 model are aluminum alloy, with a combined weight of approximately 36 lbs. Allowing 10 lb for other aluminum parts throughout the car, a total weight of aluminum parts for the car would be around 106 lbs, or about 4 1/2% of the 2360 lb. est. dry curb weight.

A similar inspection of plastic parts for the 1975 Vega car yields an estimate of 75 lb, or 3.1% of the dry curb weight. This percentage of plastics does not differ much from that of standard size cars.

Very approximately, about half the aluminum used in the Vega is for parts normally made of steel (bumpers) and about half would normally be cast iron or malleable iron. Composition estimates for small cars will therefore be reduced accordingly for iron and steel. Percentages of alloy steels (gears, springs, ball and roller bearings) would be expected to remain similar to those for full size cars.

Weights of rubber include mostly tires; tires alone account for about 3.8-4% of the weight of cars "A" and "B," but 4.4 to 5% for small cars "C."

Thus if total rubber products are 4.5% for classes "A" and "B," it would be expected to be on the order of 5.5% for "C."

From considerations such as the above, Table A12 has been constructed as the baseline "typical" materials composition of each of the three classes of 1975 automobile. The table includes an additional column representing a sales-weighted composite car for 1975. The composite car's properties were derived by sales-weighted calculations based upon sales statistics for the first seven months of 1974 (11). Including imported cars, these were estimated as 45% Class "A," 29% Class "B," and 26% Class "C." The calculated dry materials weight of the composite car was 3,390 lb, which has been rounded off to an even 3,400 lb. Percentages and weights of each material were then computed (sales weighted), and rounded off in recognition of the hypothetical nature of these estimates.

Our estimates of the composite car are in reasonable agreement with a number of literature sources describing the amounts of material in recent model cars. These include references to around 61% steel and steel alloys (21), 80 to 108 lb. aluminum in 1972-1974 cars (9,21,31) and 85-150 lb. of plastics per car (26,27,28).

TABLE A12

BASELINE MATERIALS COMPOSITION: TYPICAL 1975 MODEL AUTOMOBILES SOLD IN THE UNITED STATES

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted)	
	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%
Low Carbon Steel	2400	55.3	1659	55.3	1186	54.4	1896	55.3
Alloy Steel[b]	260	6.0	180	6.0	131	6.0	206	6.0
Total Steel	2660	61.3	1839	61.3	1317	60.4	2102	61.3
Cast Iron[c]	716	16.5	495	16.5	316	14.5	557	16.2
Aluminum	117	2.7	81	2.7	87	4.0	99	2.9
Copper, Brass	40	0.9	30	1.0	25	1.1	34	1.0
Zinc	35	0.8	24	0.8	17	0.8	28	.8
Lead	25	0.6	22	0.7	20	0.9	23	.7
Other Metal[d]	10	0.2	8	0.3	10	0.5	9	.3
Rubber	195	4.5	135	4.5	120	5.5	159	4.6
Glass	100	2.3	75	2.5	60	2.8	83	2.4
Plastic	150	3.5	105	3.5	76	3.5	119	3.5
Other Non-Metal	292	6.7	186	6.2	132	6.0	223	6.5
Totals[e]	4340	100.0	3000	100.0	2180	100.0	3430	100.1

Notes

(a) Assuming 48% Class "A," 30% Class "B," 22% Class "C" (see Arin 'Projections of Automobile Sales by Weight Class Appendix B, 30 April 1975)

(b) Including stainless steels.

(c) Including malleable iron.

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights of cars A, B, and C from Table V.

A.4 FUTURE TRENDS IN MATERIALS COMPOSITION

A.4.1. Changes that are Possible

The next five years -- 1975 to 1980 -- are coincident with the implementation of the motor industry's voluntary plan to increase fuel mileage by 40% (15). Many changes will be expected during this five year period. Those of direct concern in this study include:

1. The size of passenger cars will become smaller, particularly the category "A" full size cars.

2. The weights of cars will decrease. Partly, the reduced weight will come from the size reductions. Important weight savings will also be achieved through the substitution of light materials (particularly aluminum and plastics) for some of the iron and steel now used.

3. The mix of large, medium, and small cars (classes A, B, C) will probably change.

A combination of the three important factors given above will have to be considered in defining the composite autos of 1980 and 1990.

A.4.2 Effects of Size Changes

In order to evaluate the effect of size reduction alone, it will first be assumed that the engine and drive train remain unchanged and that the passenger room in each car class remains undiminished. The principal changes would then be to reduce the overall length of the vehicle, and to reduce the wheelbase toward the lower values already existing in each class. Some reduction of luggage space may occur, although much can be done to improve vehicle packaging so that this penalty is minimized. The overall height of cars is not likely to change redically over the five year period, but the outside width could be reduced without sacrificing hip room. The doors on some 1975 U.S.-produced autos are ten inches thick, for example. While this dimension should be viewed in the light of safety requirements, door thicknesses could probably be reduced to six inches or less. The width of the car could be reduced as much as eight inches, then, without diminishing hip room.

Referring to the previous Table A8 , the weight of the body is around 41-42% of the total car weight for full size cars. The overall length of a typical category "A" sedan is around 220 inches (18.3 ft). The wheelbase is typically 121 inches. By comparison, the Mercedes-Benz 450 SE is 195 inches long on a 113 inch wheelbase, and yet interior dimensions are similar to U.S. full size sedans.

Any forecast of the future dimensions of category "A" autos would be a guess at best. William L. Mitchell, Vice President in charge of Design at General Motors, states that "conditions are changing my job by the hour" (32). Noting, however, the decided trend toward European dimensions and car weights, we would expect category "A" cars to become at least a foot shorter (208 inches) by 1980. This is about a 5% shortening, and it would be reasonable to suppose that body structures would be reduced by a similar percentage. Thus, if 42% of the present 4340 lb. weight of car "A" or 1823 lb represents the body, about 91 lb would be saved through body shortening alone. If other design changes were incorporated such as a modest decrease in exterior width (but no materials substitution considered as yet), a weight reduction of around 120 lb should be reasonable by 1980.

Similar reasoning could be applied to cars "B" and "C," but with a decreasing potential for reducing exterior dimensions, respectively. Many small cars "C" indeed have almost no potential for shortening, being very excellent examples of efficient packaging already. This is particularly true of vehicles like the Volkswagen "Rabbit," having a transverse front engine mounting combined with front wheel drive. As a class, the average car "C" will become shortened to the extent that more manufacturers might switch from the Vega-Pinto-Toyota type design (conventional) to the new "box shape." The two-door Ford Pinto is 169 inches long, compared to the four-door "Rabbit" at 155.3 inches. While this represents a shortening potential of about 8%, perhaps only about a quarter or one-third of the cars will make such a change by 1980. This translates to a weight saving of only 20-25 lb typically for the class, considering dimensional changes only. Quite possibly, some of the potential savings in weight will be offset by future refinements for better crashworthiness in small cars.

The weight-saving potential for the typical compact car "B" through dimensional shaving alone would be 80 lb or more.

The above discussion was in consideration of the average or typical car in its class. Obviously the heavier, larger cars in each class can benefit to a much greater extent from dimensional changes. Several hundred pounds could be saved paring the dimensions of the larger standard sedans (all the more so for large station wagons). In some cases, more than two feet could be cut from the overall length.

A.4.3 Design Interactions and Design Improvement

Weight savings beget other and secondary weight savings. The foregoing discussion presented too crude a view, inasmuch as it ignored design interactions such as the following:

1. A lighter body structure (say through a reduction in length) can be adequately supported by redesigned and somewhat lighter suspension and chassis components.

2. A shorter body is a relatively stiffer structure - both in resisting twisting and bending. Or, the same stiffness can be obtained with less metal (which lightens the body still more, etc.).

3. The vehicle thus lightened requires less propulsion energy, so that successive design refinements can show the way toward lighter powerplants, drive trains, and the chassis components which carry them.

Other studies have shown the approximate magnitude of this compounding effect (24, 37). If the upper structure of the car (the body and engine compartment) are reduced in weight by one lb, an additional saving of 0.5 to 1 lb can theoretically be made in the engine, transmission and drive train, chassis, brakes, wheels and tires, etc. As a conservative statement, one pound of direct weight saving in the upper structure can reduce the vehicle's total weight by 1.5 lb.

Advanced design techniques, such as finite element structural analysis, can become powerful instruments in the business of weight reduction (24). These techniques have permitted clearer insights into the behavior of complex structures under both static and dynamic loadings. It then becomes possible to prescribe thinner gauge metal in regions which are not critical from the standpoint of strength, stiffness, or buckling criteria. It is also possible to design the various structural elements in the most advantageous geometries. These design improvements permit the materials to be used in the most efficient manner, and hence weight is reduced perceptibly.

A.4.4. Effect of Design Trade-Offs and Governmental Regulation

The need for energy conservation will urge car weights downward in each car category, and will urge some consumers to migrate from larger to smaller car categories. Other considerations, however, may place conflicting demands upon the auto designer.

Regulations relating to safety and damage limitation have resulted in recent increases in car weights and costs. Bumpers capable of withstanding a 5 mph impact have recently been mandated, resulting in substantial weight increases to virtually every car sold in the U.S. The Federal Government has "10 mph bumpers" under consideration (33). Paradoxically, the National Highway Traffic Safety Administration also has proposed a reduction in bumper capabilities, from five to 2.5 mph impact speeds. General Motors has indicated that such a roll back of standards could permit the trimming of at least 60 lb from 1976 models (34). The outcome of such regulatory standards will obviously affect the weight and composition of cars projected for 1980 and 1990.

Present and future emissions standards may have but a minor impact upon a vehicle's weight, but they do influence the materials composition. The use of stainless steel canisters for catalytic convurters, the catalytic materials themselves, and ceramic substrate materials are examples. The addition of a second catalytic device may be needed in the future to control nitrogen oxides, but it now appears that stricter NO_x standards have been deferred until at least 1980.

If the 55 mph speed limit is indeed permanent, adequate performance can be provided with smaller engines and drive components in the future. A return to predominately six-cylinder engines for compact cars "B" (from

V-8 engines) is a probability before 1980. Indeed, many cars in the "B" category demonstrate reasonably good road performance with only four-cylinder engines (Volvo, Saab, Mercedes-Benz, Toyota).

While decisions on bumper standards may influence the 1980 projected car weights by the order of ± 60 to 100 lb, engine options will have an even greater influence. A range of engine weights that might be considered for a hypothetical category "B" car could span a difference of 300 lb.

A.4.5. Materials Substitution

Materials substitution, insofar as it is driven by weight-saving considerations, involves mainly the following options:

1. Aluminum or plastics, replacing steel in structural applications.
2. Aluminum, replacing copper in radiators and electrical wiring.
3. Aluminum, replacing cast or malleable iron in engine blocks, cylinder heads, clutch housings, and transmission cases.
4. High-strength steel, replacing ordinary mild steel as a structural material.

A number of substitutions have already taken place in automotive design, driven largely by cost considerations:

1. Plastics (often plated plastics), replacing zinc-based die castings for grilles, handles, decoration, and trim.
2. Aluminum, to some extent, has replaced steel and zinc for similar nonstructural applications.
3. Plastics have replaced steel for many under-hood components, such as blades, fan shrouds, and air filter covers.

Some substitutions can result in components which are lighter, cheaper, and possess yet other advantages such as corrosion resistance. An example would be fiber glass fender well liners, replacing steel.

While not being a materials substitution in the strict sense, it is worth noting that some cars are beginning to appear with thinner glass in windows and windshields. This is claimed to save up to 20 pounds in some models (35).

The two materials likely to make the largest inroads by 1980 appear to be aluminum and plastics. Therefore, our study will concentrate on these two lightweight substitute materials.

A.4.6 The Potential Use of Aluminum

Specific case studies of weight savings by the substitution of aluminum for other materials are given below. Statistics such as these will be used in the estimates of auto materials composition for the years 1980 and 1990.

Engine Block - The Chevrolet Vega features a four-cylinder engine with a die cast aluminum alloy cylinder block. The machined weight of the aluminum block is 36 lb, which is 51 lb lighter than an equivalent cast iron block. The weight reduction is attributed to a combination of lighter materials and the greater precision of the die casting process when compared with iron foundry practices (30).

Auto Hood - Researchers at the Owens-Corning Technical Center (Granville, Ohio) determined the comparative weights of an intermediate size hood if made with a choice of materials: (Ref. 36).

Steel-----------------------------------75 lb

Aluminum--------------------------------37 lb
Fiber glass/plastic (two-piece)---------47 lb
Fiber glass/plastic (one-piece)---------34 lb

Body Parts and Bumpers - Cochran (37) has cited the following weight differences in aluminum vs. steel components:

	Weight in lb	
	Aluminum	Steel
Hood	35	90
Trunk Lid	30	75
Doors (4)	100	250
Front Fenders (2)	60	140
Bumpers (2)	50	130

Radiator - Most automobile radiators are made of copper and brass, and are assembled with tin-lead solder. A typical auto radiator weighs around 25 lb (car types "A" or "B"). According to the Aluminum Company of America, (38) an aluminum radiator would weigh about 10 pounds less. The 1975 Volkswagen "Rabbit" cars use an aluminum radiator.

Intake Manifold for Engine- The diecast aluminum intake manifold used in Ford Mustang II and Pinto cars is said to weigh 15 lb less than a cast iron manifold (39).

Transmission Case - The use of aluminum for the housings of both manual and automatic transmissions has become commonplace.

Wheels - Aluminum alloy and magnesium alloy wheels have been available for many years as automotive accessory items. A comparison of aluminum and steel "sport type" wheels shows that the aluminum wheels are 65%-85% of the weight of steel wheels of the same design type. (40) High safety factors are required for wheels of this type, since they are often used for racing purposes. Additional weight reductions are no doubt possible for wheels intended for normal driving.

A.4.7 Increase in Aluminum Usage

Commentators from the aluminum industry have predicted a rise in aluminum from 82 lb. per car now (1974-75) to 200 lb per car sometime in the period 1980-1983 (9,31). Apparently these are cautious estimates, for McGowan of the Aluminum Company of America states, "Aluminum companies know Detroit as an unemotional place. Competition is real and cost is important. The auto industry manufactures the most evolutionary product in the world ...." (31). Implied is that the aluminum industry foresees a steady rise in aluminum deliveries to auto manufacturers, but no revolutionary quantum jumps. The Aluminum Association apparently shares this view for the period through 1980, but forecasts a disproportionate increase in the use of aluminum in bodies and engines by 1985 (see Table A13, from Ref. 9). An average aluminum usage of about 575 lb per intermediate class passenger car is foreseen in 1985 by that organization.

A.4.8 The Use of Plastics in Automobiles

The weight of plastics in the average U.S. auto increased slowly, from about 10 lb in 1950 to around 30 lb in 1965. But then, this figure rose sharply to 100 lb per car by 1970 (29). Stewart Frey, of the Ford Motor Co., observes that while some have forecasted an increase to 300 lb

TABLE A13

Estimated Average Usage of Aluminum in Intermediate Class Passenger Cars[a]

(Source: The Aluminum Association, See Ref. 9)

	Current		Potential			
	1974		1980		1985	
Item	lb	kg	lb	kg	lb	kg
Castings	57.25	25.97	67.00	30.39	206.25	93.56
Trim	8.90	4.04	9.00	4.08	12.90	5.85
Air Conditioners	8.10	3.67	11.00	4.99	12.00	5.44
Bumpers	4.25	1.93	35.00	15.88	50.00	22.68
Body Sheet	0.22	0.10	58.00	26.31	255.00	115.67
Miscellaneous	3.58	1.62	20.00	9.07	39.60	17.96
Total	82.30	37.33	200.00	90.72	575.75	261.16

(a) "Intermediates" are included with Category "A" cars discussed in this study.

per car by 1980, a more reasonable estimate might be 200 lb per vehicle (28). Reasons for the lower figure include the energy crisis, supply shortages, and a trend toward smaller cars.

Plastic Auto Bodies - At least one production vehicle (Chevrolet Corvette) and a number of experimental cars have featured bodies constructed almost entirely from plastic materials. While Detroit has shown a general reluctance to switch to all-plastic bodies in high-volume production, much experience has been gained over the years with the fiber glass-bodied Corvette in both field and factory. A further experimental step was taken in the development of Chevrolet's XP-898 sports car prototype (42). This car is a small, low-silhouette, two-seater with a removable roof. Vega components are used in the powertrain. A sandwich construction of fiber glass reinforced plastics over a urethane foam core is used to form the unitized chassis-body structure. Some of the dimensions and weights of the XP-898 are:

Wheelbase: 90 inches
Overall Length: 162 in
Overall Height: 42.5 in
Body/chassis structure weight: 350 lb
(100 lb of polyurethane foam)
Total vehicle curb weight: 2285 lb

The predominately-plastic body-chassis unit is 15.3% of the total vehicle weight. The body-chassis employed a minor amount of steel, principally front and rear subframe elements to which suspension components were fastened.

Fender Liners (Wheel Wells) - If the liner is primarily used in the non-structural sense of providing only splash and impact resistance, a 50% reduction over the weight of a steel counterpart is possible. A 0.032 inch gauge sheet steel part weighs typically 10 lb. A replacement made of unreinforced polypropylene should be four times as thick (0.125 in), but with a density 1/8 that of steel, would weigh only about 5 lb. In some cars, the fender liners also serve as integral structural members. For such an application, a fiber glass reinforced plastic would be used. This would raise the weight, but a weight saving per liner of about 3 pounds is still possible (27).

Auto Hoods - Earlier in this chapter, a study of steel vs. aluminum vs. fiber glass plastic hoods was discussed (36). Comparative weights were 75 lb. in steel, 37 lb in aluminum, and 34 lb (one-piece plastic construction) or 47 lb (two-piece plastic construction). Thus it appears that large body modules or panels in either aluminum or reinforced plastics can result in a 50% weight reduction when compared with steel. Presumably, similar reductions could be made in such modules as doors and trunk lids.

Other Body Parts - In the 1973 model year, the Chrysler Newport had a three-piece metal front end weighing a total of 22 lb. A redesign of the front end, as a single piece of fiber glass plastic, resulted in a weight savings of 10 lb (45% reduction) (36). The new Ford Granada and Mercury Monarch each are fitted with single-piece, 10 lb front end panels.

An original zinc die casting (1973 Pontiac side window louvre) weighing about 20 lb was replaced by an injection molded fiber glass-reinforced thermoplastic polyester part weighing less than 5 lb; this was a 75% weight reduction (36).

Soft Body Parts - Flexible exterior body panels, such as filler panels, fender extensions, and fascia have recently been introduced. Rub strips, bump strips, and flexible front and rear panels are other potential plastics applications. High impact resistant, highly flexible polypropylene, or the thermoplastic urethanes, or vinyls are suitable. (27) Liquid reaction-molded urethane is being used to form the flexible front and rear fascias of the 1975 Chevrolet Monza 2+2. (41).

Bumpers - Increasing amounts of plastics will find their way into the bumper systems of automobiles. Two uses are as the main structural material, and as an energy-absorbing material in the bumper supports. Three Renault models have fiberglass/plastic bumpers for 1975.

Fuel Tank - Volkswagen has developed a plastic fuel tank for its new Passat series front wheel drive cars. The fuel tank is fabricated from tough, shock-resistant polyethylene by a blow molding process. The plastic tank weighs eight pounds, and has a capacity of 13 gallons. A comparable steel tank weighed 11.3 lb (29% weight saving). A referenced report describes the extensive safety and proof testing of this tank (43).

A.4.8. Projected Auto Materials Composition -- 1980

For each of the three car categories (A,B,C), three estimates of materials composition will be made:

1. Example with maximum credible aluminum content for 1980.
2. Example with maximum credible plastics content for 1980.
3. Examples of the most probable composition for 1980.

Examples (1) and (2) above are not to be construed as maximum possible content of aluminum and plastics content, respectively. One can imagine that it is possible to make virtually the whole car from aluminum, save for the windows, tires, and certain mechanical parts. Likewise, it is possible to make an almost complete car from plastics (including replacement of the glass with clear plastic), except for highly stressed parts of the chassis, and the engine and drive train. Perhaps some cars will approach these extremes in the more distant future, but such radical changes are not expected to impact upon the market by 1980.

Cars for the model year 1980 are scheduled for introduction during the latter half of 1979, and will be in the active design stages in 1976. Many basic decisions regarding the design, materials, and tooling must be made in not much more than a year from the date of this forecast. Radical changes from current practice are therefore unlikely, at least on an industry-wide scale.

We can be fairly certain that the basic body structure of most 1980 model cars will be fabricated by techniques and from materials used on today's assembly lines. The basic structure will be assembled from steel stampings by welding.

Modules added to the basic body structure -- doors, hood, trunk lid, fenders, fascia, and trim components -- could very well be of substitute materials. A steel, aluminum, or plastic hood could be installed interchangeably on the basic steel body structure at any desired time -- even in the middle of a model year. The process and equipment used in hanging the doors would not change. Some or all of such module changes are likely to occur by 1980 on many car models. The problem in forecasting is that most of such modules could be made in either aluminum or plastics with about the same weight savings over steel. Aluminum and some stampable plastics can even be formed by the same tooling now used to make steel parts. Possibly small differences in energy, cost, and availability between the two materials will decide which material is favored. Aspects of recycling the materials may influence the decision. Subsequent tasks of this study will shed more light on that subject.

More and more engine blocks, cylinder heads, and intake manifolds are likely to be redesigned in aluminum. The amount of cast iron in cars is likely to diminish. Transmission housings are frequently made of aluminum at the present time.

Aluminum radiators, replacing a portion of the copper used in cars today, are likely to become popular. A good many aluminum air conditioner condensers (which resemble radiators in construction) are already in use.

Assumptions Made in the Forecast - The following basic assumptions will be made in portraying the "average" 1980 model automobile in each of the three size categories:

1. Cars in each category will become somewhat smaller in size and lighter in weight, whether or not light weight materials are substituted. This influence will be more pronounced in the larger car categories.

2. Since energy shortages are likely to continue, and with manifestations such as permanently lowered speed limits, it is predicted

that smaller, less powerful engines will be in use by 1980. This would reduce engine weight (we have assumed up to 10%) irrespective of materials chosen.

3. The basic "body cage" including roof and floor will still be of predominately welded steel construction through at least the 1980 model year.

4. Light materials, either plastic or aluminum, will be substituted for steel (on at least some car models) via the modular parts such as doors, hood, trunk lid, etc.

5. Certain other substitutions were also assumed, such as the possible beginning of the introduction of plastic fuel tanks on U.S. manufactured cars, the introduction of aluminum radiators, and aluminum wheels. Such wheels may remain optional items if manufacturing costs remain higher than steel wheels, however. Five wheels and five tires were used in all calculations.

6. Weight savings in substituting plastics or aluminum for steel, copper, iron, or zinc are assumed to be similar to those given in the examples cited in the text. One pound of the conventional materials can be replaced by 0.3 to 0.6 lb of either plastics or aluminum, depending upon the application, requirements for stiffness, etc.

7. As an example of market penetration of substitute materials, we projected the substitution of aluminum for some of the cast iron and malleable iron. It was assumed that 80% of such iron was potentially replaceable by aluminum. Of that which is potentially replaceable,

it was assumed that aluminum will make a 60% market penetration by 1980 in the "maximum credible aluminum" case. It was assumed that this penetration would be 20% in the "most probable" case. The 20% penetration was also assumed for the replacement of cast iron engines for the "maximum plastics" car.

8. The following assumptions were made for the replacement of steel body modules (hood, trunk lid, average of three doors between 2-dr. and 4-dr. types, two fenders, etc.)
    - "Maximum Aluminum Cars": 50% market penetration by aluminum, 10% by plastics
    - "Maximum Plastic Cars": 50% market penetration by plastics, 10% by aluminum.
    - "Most Probable Composition": 20% penetration each by aluminum and plastic by 1980.

    (Percent penetration refers to the weight of conventional materials replaced.)

9. Glass weight can be reduced up to 17% by the use of thinner high-strength glass.(44) Weight savings might be partially offset by larger glass areas in 1980. We therefore assumed a 1980 glass weight of 95% of the 1975 baseline.
10. After the first iteration of weight calculations, an allowance for secondary weight savings was applied. As explained earlier, each pound of weight saved can result in an additional saving of one-half pound in the weight of support structure, powerplant, and drive train. In a second iteration, therefore, one-half of the potential secondary saving was distributed proportionately among the steels, iron and rubber. We discounted the full potential for secondary savings because of possible offsetting factors such as more stringent future safety requirements.

The results of the forecast are given in the following three tables. Table A14 gives the weight breakdowns for the assumed maximum credible aluminum content. Table A15 gives the breakdown for the maximum credible plastics content. Finally, Table A16 gives the estimated figures for the most probable average materials content for each car category. In addition to the three primary auto categories, an estimate is made for the sales-weighted composite auto as visualized for the model year 1980. This assumes 30 % Class A, 37 % Class B, and 33 % Class C automobiles will be the sales distribution, including imports.

A.4.10 Projected Auto Materials Composition - 1990

In a similar manner, projections were made for the model year 1990. A major assumption was that a need to conserve materials and fuel energy will continue to drive car weights downward through the decade following 1980. Further reductions in weight were assumed to come mainly through increased market penetrations by aluminum and plastics. For the maximum credible aluminum and maximum credible plastics cases, we assumed a virtually complete penetration into the market for hung-on body modules(doors,hoods, etc.) and the beginnings of inroads into the market for the basic body structure itself. For the "most probable" case, we assumed a 40% penetration each by plastics and aluminum into the potential model market (80% of the steel doors, hoods, etc. replaced by light materials).

Some reduction in the use of rubber was forecast, to allow for the possible phase-out of spare tires.

A modest increase in alloy steels is shown to reflect the possible beginnings of the introduction of advanced, alternative propulsion systems by 1990.

TABLE A14

PROJECTED MATERIALS COMPOSITION: 1980 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE ALUMINUM CONTENT

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%
Low Carbon Steel	1792	49.6	1184	47.7	909	47.9	1276	48.6
Alloy Steel (b)	247	6.8	171	6.9	126	6.6	179	6.8
Total Steel	2039	56.4	1355	54.6	1035	54.4	1455	55.4
Cast Iron(c)	307	8.5	224	9.0	153	8.0	225	8.6
Aluminum	419	11.6	312	12.6	244	12.9	322	12.3
Copper, Brass	25	.7	18	.7	16	.8	19	.7
Zinc	17	.5	12	.5	9	.5	12	.4
Lead	25	.7	22	.9	20	1.1	22	.8
Other Metal (d)	20	.6	20	.8	20	1.1	20	.8
Rubber	188	5.2	129	5.2	117	6.2	143	5.4
Glass	95	2.6	71	2.9	57	3.0	74	2.8
Plastic	234	6.5	161	6.5	114	6.0	167	6.4
Other Non-Metal	242	6.7	156	6.3	112	6.0	167	6.4
Totals (e)	3611	100.0	2480	100.0	1897	100.1	2626	100.0

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE A15

PROJECTED MATERIALS COMPOSITION: 1980 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE PLASTICS CONTENT

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%
Low Carbon Steel	1849	48.9	1228	47.1	944	47.6	1321	48
Alloy Steel (b)	250	6.6	173	6.6	127	6.4	181	6.6
Total Steel	2099	55.6	1401	53.7	1071	54.0	1502	54.6
Cast Iron (c)	520	13.8	380	14.6	257	13.0	381	13.9
Aluminum	196	5.2	140	5.4	128	6.5	153	5.6
Copper, Brass	35	.9	26	1.0	22	1.1	27	1.0
Zinc	17	.5	12	0.5	9	0.5	12	0.4
Lead	25	.7	22	0.8	20	1.0	22	0.8
Other Metal (d)	20	.5	20	0.8	20	1.0	20	0.7
Rubber	188	5.0	130	5.0	118	6.0	143	5.2
Glass	95	2.5	71	2.7	57	2.9	74	2.7
Plastic	340	9.0	247	9.5	168	8.5	249	9.1
Other Non-Metal	242	6.4	156	6.0	112	5.7	167	6.1
Totals (e)	3777	100.0	2605	100.0	1982	100.2	2750	100.1

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE A16

PROJECTED MATERIALS COMPOSITION: 1980 MODEL AUTOMOBILES

BASIS: MOST PROBABLE MATERIALS CONTENT

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt., lb	wt %	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%
Low Carbon Steel	1977	51.2	1332	49.8	1006	49.7	1418	50.4
Alloy Steel (b)	251	6.5	174	6.5	128	6.3	182	6.5
Total Steel	2228	57.7	1506	56.3	1134	56.0	1600	56.9
Cast Iron (c)	523	13.5	383	14.3	259	12.8	384	13.6
Aluminum	229	5.9	166	6.2	146	7.2	178	6.3
Copper, Brass	35	0.9	26	1.0	22	1.1	27	1.0
Zinc	17	0.4	12	0.4	9	0.4	12	0.4
Lead	25	0.6	22	0.8	20	1.0	22	0.8
Other Metal (d)	20	0.5	20	0.7	20	1.0	20	0.7
Rubber	189	4.9	131	4.9	118	5.8	144	5.1
Glass	95	2.5	71	2.7	57	2.8	74	2.6
Plastic	261	6.8	182	6.8	128	6.3	188	6.7
Other Non-Metal	242	6.3	156	5.8	112	5.5	167	5.9
Totals (e)	3864	100.0	2675	99.9	2025	99.9	2816	100.0

Notes

(a) Assuming 30% Class "A"; 37% Class "B"; 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

We decided to keep the distribution of car sizes the same as for 1980, believing that the market will stabilize in this respect before 1980. (The market may even temporarily overshoot in favor of subcompacts and then swing back toward vehicles that will at least accommodate a family of five.)

Tables A17, A18 and A19 show the forecasted materials compositions for the three car size categories and for the hypothetical sales-weighted composite automobile of 1990.

A.4.11 Comments on Projections

The dry curb weight of the "most probable" 1980 full sized car "A" is predicted to be 476 lb lighter than the 1975 baseline car "A". By 1990, these cars may become 870 lb lighter than 1975. The recently announced goal of the Federal government, to improve automobile fuel economy by 40% by the 1980 model year, is a uniformly-applied and strong motivating force toward smaller and lighter cars. Our predictions are therefore clearly in the right direction, and the weight savings are of about the same magnitude as those predicted by the motor industry.

It is interesting to observe that full sized cars may return to the weights of such vehicles manufactured in the 1950's (See Fig. A1). The average weights of compact and small cars will approach the weights of cars currently being manufactured abroad. The evolution of European and Japanese cars always has been influenced by the need to conserve fuel and materials.

TABLE A17

PROJECTED MATERIALS COMPOSITION: 1990 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE ALUMINUM CONTENT

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt., lb	wt. %	wt., lb	wt. %	wt., lb	wt. %	wt., lb	wt. %
Low Carbon Steel	1198	38.4	760	35.5	594	36.7	837	37
Alloy Steel (b)	272	8.7	188	8.8	139	8.6	197	8.7
Total Steel	1470	47.1	948	44.3	733	45.3	1034	45.7
Cast Iron (c)	135	4.3	87	4.1	43	2.6	87	3.8
Aluminum	720	23.1	530	24.8	398	24.6	543	24.0
Copper, Brass	19	0.6	13	0.6	12	0.7	15	0.7
Zinc	10	0.3	8	0.4	6	0.4	8	0.4
Lead	20	0.6	18	0.8	17	1.1	19	0.8
Other Metal (d)	35	1.1	35	1.6	35	2.2	36	1.6
Rubber	158	5.1	127	5.9	101	6.2	128	5.7
Glass	90	2.9	68	3.2	54	3.3	70	3.1
Plastic	242	7.8	167	7.8	118	7.3	173	7.6
Other Non-Metal	218	7.0	140	6.5	101	6.2	151	6.7
Totals (e)	3117	99.9	2141	100.0	1618	99.9	2264	100.0

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE A18

PROJECTED MATERIALS COMPOSITION: 1990 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE PLASTICS CONTENT

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted)(a)	
	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%
Low Carbon Steel	1319	40.5	825	37.3	675	40.0	924	39.3
Alloy Steel (b)	275	8.4	173	7.8	127	7.5	188	8.0
Total Steel	1594	48.9	998	45.1	802	47.5	1112	47.3
Cast Iron (c)	290	8.9	200	9.0	119	7.1	200	8.5
Aluminum	296	9.1	214	9.7	178	10.6	227	9.7
Copper, Brass	19	0.6	13	0.6	12	0.7	14	0.6
Zinc	10	0.3	8	0.4	6	0.4	8	0.3
Lead	20	0.6	18	0.8	17	1.0	18	0.8
Other metal (d)	35	1.1	35	1.6	35	2.1	35	1.5
Rubber	158	4.8	127	5.7	101	6.0	128	5.4
Glass	90	2.8	68	3.1	54	3.2	70	3.0
Plastic	530	16.3	392	17.7	262	15.6	390	16.6
Other Non-Metal	210	6.7	140	6.3	101	6.0	150	6.4
Totals (e)	3260	100.1	2213	100.0	1687	100.1	2352	100.1

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin , magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE A19

PROJECTED MATERIALS COMPOSITION: 1990 MODEL AUTOMOBILES

BASIS: MOST PROBABLE MATERIALS CONTENT

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	1649	47.5	1074	45	837	46.3	1168	46.3
Alloy Steel (b)	276	8.0	191	8	141	7.8	200	7.9
Total Steel	1925	55.5	1265	53	978	54.1	1368	54.2
Cast Iron (c)	290	8.4	200	8.4	119	6.6	200	7.9
Aluminum	389	11.2	289	12.1	228	12.6	299	11.9
Copper, Brass	19	0.5	13	.5	12	.7	14	0.6
Zinc	10	0.3	8	.3	6	.3	8	0.3
Lead	20	0.6	18	.8	17	.9	18	0.7
Other Metal (d)	35	1.0	35	1.5	35	1.9	35	1.4
Rubber	158	4.6	127	5.3	101	5.6	128	5.0
Glass	90	2.6	68	2.8	54	3.0	70	2.8
Plastic	316	9.1	228	9.5	156	8.6	231	9.2
Other Non-Metal	218	6.3	140	5.9	101	5.6	151	6.0
Totals (e)	3470	100.1	2391	100.1	1807	99.9	2522	100.0

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

It was perhaps most interesting to discover that the weights of the most probable composite car may fall by an amount greater than that of any car category - more, even, that for category "A" cars. This reflects the strong influence of possible consumer migration away from the larger cars. The mix of 1980 and 1990 new cars is expected to contain considerably fewer category "A" cars, and correspondingly more cars in the "B" and "C" categories. The percentage mix is expected to stabilize over the period 1980-1990; some six passenger cars will still be needed to serve the requirements of some families.

A.4.12 Effect Upon Manufacturing Methods

We do not expect that the substitution of plastics or aluminum for steel will, in itself, call for change in the techniques and equipment used on the main assembly lines. At least through 1990 and quite likely until 1990, the basic body structure will remain of welded steel construction. Advances can be anticipated for reasons other than materials substitution, however. The rising cost of labor will drive the industry toward more and more automation on the assembly lines. The trend will be toward the procedures and equipment now in use in the manufacture of the Chevrolet Vega at Lordstown, Ohio (30):

1. Automated body assembly permits a manufacturing rate of 100 cars/hour, which is twice the rate of earlier methods.
2. Of the 3,900 body welds on the Vega, 95% are now completed automatically.
3. Modular design eases automated assembly. As many large panels and subassemblies as possible are incorporated.

4. Modules such as doors are hung automatically.

The modular design approach allows much flexibility in choosing alternative materials. Materials changes can even occur during the course of a model year without great disruption of the main assembly line. Modules such as assembled doors, trunk lids, hoods, bumper assemblies, etc. can be built in an ajoining fabricating plant, in off-line areas of the assembly plant, or purchased from suppliers.

Aluminum sheet metal parts may be stamped in high volume with the same type of machinery and even with the same tooling as with sheet steel. Welding and fastening techniques will differ, however. Because the welding of aluminum may be higher in cost than the welding of steel, newly developed techniques of adhesive bonding may be adopted. (45)

Improved methods of high-volume die casting are being applied to aluminum parts such as engine blocks and transmission housings. (30,39). Much of the traditional sand-molding foundry work will thus be displaced.

Large changes will be required on the part of the radiator and heat exhanger industry. Soldered copper and brass radiators will be potentially replaced with vacuum brazed aluminum units.

An especially attractive feature with regard to the plastic modules is that manufacturing methods are available for a wide range of production quantities. "Soft" tooling for small-volume production of plastic body panels can be had for as low as 5% of the cost of tooling for steel bodies (although there would be a trade-off with manufacturing labor costs). The point at which steel (hard) tooling becomes cheaper is believed to be around 60,000 units for molding fiberglass/plastic, and about 100,000 units for fabricating by thermoforming.

Soft body parts are now being produced by reaction injection of urethane components . (41) Developed in Europe, two high-pressure streams of reactants are mixed by impingement; an extremely fast chemical reaction of the materials components forms the solid part within the mold. Process cycle times are down to 2 minutes of curing time plus 2 minutes of tool handling time per part, with the possibility of further reductions of these times.

Other plastics molding processes include blow molding, injection molding, liquid molding, and rotational powder molding.

Experience with forming large automotive plastics parts is still immature. Future production costs are uncertain, but in general, cost reductions are a likely possibility. One possibility for future cost savings is the stamping of thermoplastics, using equipment of the type now used for stamping metal parts. This type of "solid phase forming" may allow rapid cycles and hence low unit costs. (46).

A.4.13 Impact Upon Automotive Longevity

Rising prices of automobiles will cause the consumer to become better informed as to the ingredients of lifetime costs. Owners will benefit directly from lightweight materials in terms of savings in fuel costs over a vehicle's lifetime. Owners will contemplate keeping their cars longer.

It is not apparent that longevity will be greatly affected by the type of materials substitutions that have been discussed. Cars probably will last longer in the future, but the major benefits will come through design and quality improvements. We can expect a continuing evolution in the improved service life of such items as tires, batteries, and electrical components. A few years ago, the life of car bodies was limited (in many sections of the country) by rust-out of the lower body panels. This already has been largely alleviated by the use of galvanized steel panels in critical areas, and by better paints, primers, and undercoatings. No doubt plastics will play a large role in upholding this improvement. Aluminum will need protective coatings or surface treatment to withstand corrosion from salty road spray.

Fender, body, radiator and engine repair techniques will change drastically with changes from steel to plastics and aluminum. Some tasks will become easier (use of plastic body fillers) but soldering, welding, and straightening may become more difficult if not precluded in some shops.

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APPENDIX B

PROJECTIONS OF AUTOMOBILE SALES BY WEIGHT CLASS

by R. W. Roig

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B.1 SUMMARY

Task I of this study is an attempt to estimate the material composition of automobiles 5 to 15 years into the future. This has been done for the "scenarios" of

1) Maximum credible aluminum content
2) Maximum credible plastics content
3) Maximum probable materials content

by Roy Renner*. A necessary step in the analysis was to define categories of cars by size (principally weight) and examine in detail the opportunities for materials substitution in each size class. A "composite" car is then defined by a sales weighted average of the size categories. This was done for both 1980 and 1990 time frames.

In order to construct the composite car, it is necessary to predict percentage sales by weight category. This is the problem addressed in this paper. A projection of this type can be based only on past trends, tempered by judgment, and no particular claim for accuracy is espoused for the results presented here.

The categories of cars defined in Renner's paper are shown in Table B1 taken from Appendix A. Fig. B1 shows % of U.S. market sales for each of these categories as derived from data obtained from the Motor Vehicle Manufacturers Association for the years 1968 through 1974 and for the first 2 months of 1975. Also shown are "eyeballed" linear trend lines to the data extrapolated to 1980.

As can be seen, the data appears to have well developed trends, with the downward trend for car A being accentuated in 1975, the upward trend for car B similarly accentuated, while for car C the data remains fairly close to its recent historical trend. Obviously a linear extrapolation cannot continue into the indefinite future. We have postulated a leveling off of the car A market share at about 30% beginning about 1979

---

*Appendix A, "Future Material Composition in Automobiles" by Roy Renner.

TABLE B1

BASELINE CAR DEFINITIONS (MODEL YEAR 1975)

	Car "A"	Car "B"	Car "C"
Description	Full Size Family Sedan	Compact	Small or Sub-Compact
No. Adult Passengers	6	5	4
Curb Weight, lb	>3,500	2,500-3,500	<2,500
Wheelbase, in	>110	98-110	<98
Total Length, in	>200	180-200	<180
Total Seating Width, in	>100	90-100	75-80
Luggage Space, ft^3	12-20	10-14	8-10
Engines:			
Typical No. Cyl.	8	6	4
Displacement, in^3	>300	200-300	<150
SAE Net HP	>140	95-120	<95
Fuel Economy, mpg*			
Urban	10-13	13-18	18-24
Highway	15-18	18-28	24-38

*By U.S. EPA dynamometer method. See Appendix A, Ref. (17).

	1968	1969	1970	1971	1972	1973	1974	1975 2 mos.
Car "A"	74.6	72.0	63.1	61.7	61.9	57.3	50.9	40.0
Car "B"	20.1	22.2	27.5	23.3	22.5	25.6	32.2	39.2
Car "C"	5.3	5.8	9.4	15.0	15.6	17.1	16.9	20.8

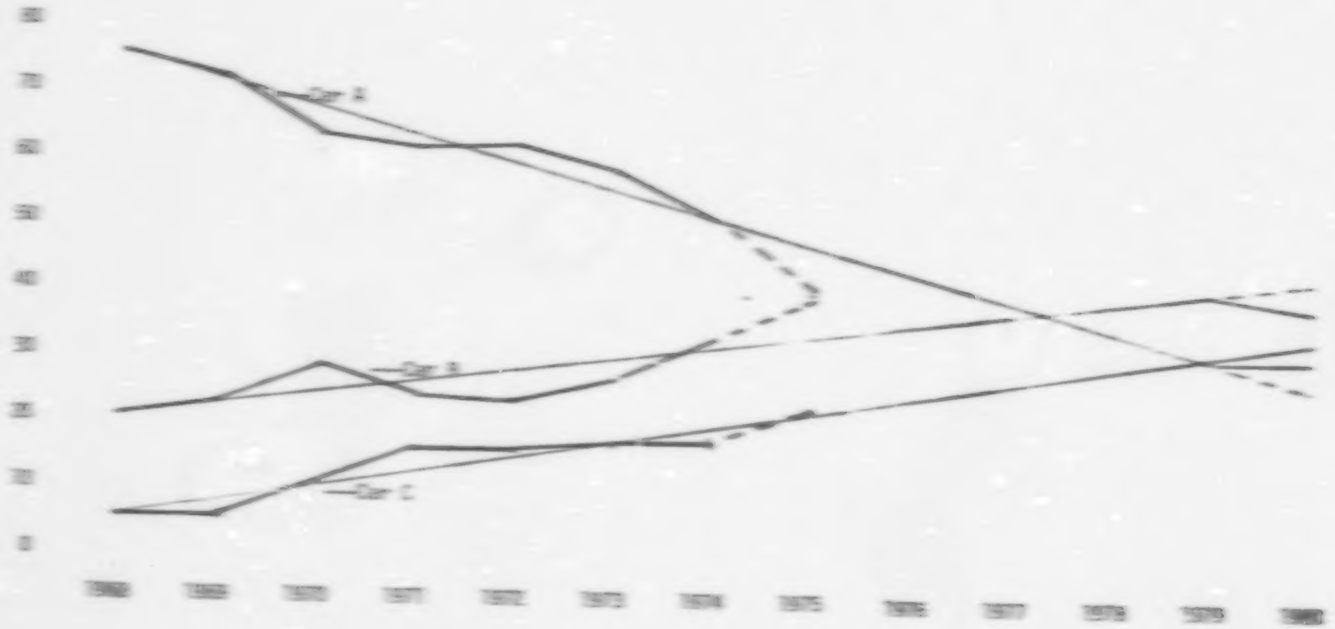

Figure 61. MVMA Data of % U.S. Market

based on the following judgments:

1) A minimal market for six passenger (or larger) cars will exist for families of five and larger, particularly for suburban households.
2) The weight of the car A category will decrease and its fuel economy improve with time, so that the incentive for individuals to substitute a B size car will decrease.
3) The status symbol value of largeness and luxury in cars will not entirely disappear. (Even though luxury cars will get smaller; e.g. Chrysler's "Cordoba" and Cadillac's "Seville," they probably will never get down to the car B size category.)

Because the car C category has shown the most consistent recent trend we have continued it to 1980. The postulated trend for car B is then the increment required to make the totals equal 100% at each point. This yields the extrapolation to 1980. Prediction beyond 1980 to 1990 appears to be too speculative to warrant anything but a simple continuation of the 1980 market shares. Market shares for 1975, 1980, and 1990 are shown in Table B2.

TABLE B2

Projected Market Shares

	1975	1980	1990
Car A	46%	30%	30%
Car B	32%	37%	37%
Car C	22%	33%	33%

B.2 MVMA DATA

The Motor Vehicle Manufacturers Association of the U.S., Inc. (MVMA) compiles data on U.S. motor car sales by a set of "classes" which are somewhat related to weight and somewhat related to price. The MVMA classes, the models included in each class and the curb weights of 1974 and 1975 models are listed in Table B3. In addition, the MVMA data list total sales of imported cars without breakdown by class. Imported car sales were apportioned evenly between car C (subcompact) and car B (compact).

Examining the weights listed in Table B3, we see that only one car (the Pontiac Astra) is really in the subcompact class based on 1975 weight. We also note that the 1974 Vega and Pinto were in that class while the 1975 models are out. In fact there appears to be a general weight increase throughout the lists when 1975 weights are compared to 1974 weights. This is probably caused in part by add-ons for safety (e.g., energy absorbing bumpers) and emission controls (catalytic converters). Most 1975 cars were well along in the design cycle before the need for fuel economy was made apparent to the auto manufacturers. We would anticipate a reversal in weight trend within class over the next decade.

Despite their slight overweight, according to the standards of Table B1 we have decided to place the MVMA "subcompact" category in our car C class. The MVMA Compact and Sport categories we have lumped into the car B class, while the Passenger Van, Intermediate, Regular, and High categories are lumped into our car A class. This causes Mercury Cougar sales to fall into the car B sales and Chevrolet Corvette sales into car A sales, while the former should be in car A and the latter in car B. The errors should roughly cancel and, in any event, sales of Cougar and Corvette are a relatively small portion of total car sales.

Table B4 shows the MVMA data from which the data in Fig B1 were computed and plotted.

TABLE B3

Car Weights
for MVMA Classes

MVMA Class	Model		1974	1975
Subcompact				
	Bobcat	Mercury	****	2615
	Astra	Pontiac	****	2499
	Vega	Chevrolet	2446	2531
	Pinto	Ford	2443	2594
	Gremlin	AMC	2739	2694
Compact				
	Pacer	AMC	****	2995
	Monarch	Mercury	****	
	Nova	Chevrolet	3254	3367
	Ventura	Pontiac	3291	3335
	Omega	Oldsmobile	3334	3471
	Apollo	Buick	3609	3383
	Maverick	Ford	2964	3017
	Granada	Ford	****	3384
	Comet	Mercury	2980	3031
	Valient	Plymouth	3115	3120
	Dart	Dodge	3135	3140
	Hornet	AMC	2893	2881
Sport				
	Skyhawk	Buick	****	2803
	Starfire	Oldsmobile	****	2937
	Monza	Chevrolet	****	2668
	Camaro	Chevrolet	3413	3616
	Firebird	Pontiac	3390	3386
	Mustang	Ford	2743	2779
	Cougar	Mercury	4275	4108
Pass. Vans				
	Voyager	Plymouth		
	Sport Van	Chevrolet		
	Club Wagon	Ford		
	Sportsman	Dodge		

TABLE B3 (cont.)

Car Weights for MVMA Classes

MVMA Class	Model		1974	1975
Intermediates				
	Cordoba	Chrysler	----	4110
	Monte Carlo	Chevrolet	4036	3927
	Chevelle	Chevrolet	3683	3778
	LeMans	Pontiac	4017	3729
	Cutlass	Oldsmobile	4040	3891
	Fury (Satellite in 1974)	Plymouth	3615	3720
	Century	Buick	4126	3730
	Torino	Ford	4092	4318
	Montego	Mercury	4092	4100
	Elite	Ford	----	4350
	Charger SE	Dodge	3725	4120
	Coronet	Dodge	3600	3885
	Matador	AMC	3536	3586
Regular				
	Impala	Chevrolet	4399	4360
	Catalina	Pontiac	4492	4247
	Grand Prix	Pontiac	4231	4032
	Olds 88		4537	4496
	Olds 98		4830	4883
	LeSabre	Buick	4541	4411
	Electra	Buick	4892	4706
	Galaxie	Ford	4341	----
	LTD	Ford	----	4550
	Marquis	Mercury	4862	4800
	Grand Fury	Plymouth	4430	4400
	Monaco	Dodge	4540	4430
	Newport	Chrysler	4630	4495
High	Corvette	Chevrolet	3390	3446
	Tornado	Oldsmobile	4838	4887
	Riviera	Buick	4732	4539
	Fleetwood	Cadillac	5298	
	Thunderbird	Ford	5033	5101
	Continental		5361	5205
	Mark IV		5327	5150
	New Yorker	Chrysler	4670	4770
	Imperial		5095	5205
	Eldorado		5105	

TABLE 84

U.S. NEW CAR DELIVERIES BY CLASSES

	1968	1969	1970	1971	1972	1973	1974
Units							
Domestic:							
Sub-compact	12,867	3,925	272,866	759,555	855,522	1,072,430	791,981
Compact	627,264	906,612	1,124,489	1,140,536	1,344,637	1,600,723	1,545,510
Sport	821,588	671,687	546,389	437,065	308,486	443,736	608,486
Passenger Van	48,567	52,755	49,178	62,055	74,529	86,453	92,398
Intermediate	2,438,481	2,205,460	1,962,996	2,005,080	2,316,651	2,466,271	2,007,586
Regular	3,978,922	3,842,138	2,867,652	3,419,328	3,480,996	3,354,287	1,962,850
High	725,665	780,759	558,667	809,762	902,261	644,211	469,797
Total Domestic#	8,624,929	8,464,395	7,335,337	8,670,286	9,321,582	9,669,689	7,448,921
Total Import	985,767	1,118,956	1,277,426	1,556,676	1,615,909	1,766,238	1,420,436
Grand Total	9,610,596	9,577,351	8,592,973	10,226,962	10,937,411	11,435,967	8,869,357
Percent of Total Domestic Makes							
Sub-compact	0.2	*	2.1	8.8	9.6	11.1	10.6
Compact	7.2	10.7	15.8	13.5	14.4	16.6	20.7
Sport	9.5	7.9	7.7	5.0	3.3	4.6	8.1
Passenger Van	0.5	0.6	0.7	0.7	0.8	0.9	1.2
Intermediate	28.5	26.0	26.2	23.1	24.9	25.5	27.0
Regular	45.7	45.4	40.5	39.4	37.3	34.7	26.1
High	8.4	9.3	7.2	9.5	9.7	6.6	6.3
Total Domestic	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Percent of Total U.S. Market							
Domestic:							
Sub-compact	0.1	*	1.8	7.4	8.2	9.4	8.9
Compact	6.5	9.4	13.4	11.4	12.3	14.0	17.4
Sport	8.5	7.0	6.5	4.3	2.8	3.9	6.8
Passenger Van	0.5	0.6	0.6	0.6	0.7	0.8	1.0
Intermediate	25.6	23.0	22.1	19.6	21.2	21.6	22.7
Regular	41.0	40.1	34.1	33.4	31.8	29.3	22.9
High	7.5	8.3	6.2	8.1	8.2	5.6	5.3
Imports	10.3	11.6	15.2	15.2	14.8	15.4	15.9
Grand Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Less than 0.1% SOURCE: Compiled by Motor Vehicle Manufacturers Association of the U.S., Inc. Revised 2/20/75

# Excluding Checker.

TABLE 8A (Cont.)
MONTHLY 1975 U.S. NEW CAR DELIVERIES BY CLASSES

	January	February	March	April	May	June	July	August	September
Units									
Domestic									
Sub-compact	[illegible]	[illegible]							
Compact	[illegible]	[illegible]							
Sport	[illegible]	[illegible]							
Passenger Van	[illegible]	[illegible]							
Intermediate	[illegible]	[illegible]							
Regular	[illegible]	[illegible]							
High	[illegible]	[illegible]							
Total Domestic*	[illegible]	[illegible]							
Total Import	[illegible]	[illegible]							
Grand Total	[illegible]	[illegible]							
Percent of Total Domestic Sales									
Sub-compact	[illegible]	[illegible]							
Compact	[illegible]	[illegible]							
Sport	[illegible]	[illegible]							
Passenger Van	[illegible]	[illegible]							
Intermediate	[illegible]	[illegible]							
Regular	[illegible]	[illegible]							
High	[illegible]	[illegible]							
Total Domestic	100.0	100.0							
Percent of Total U.S. Market									
Domestic									
Sub-compact	[illegible]	[illegible]							
Compact	[illegible]	[illegible]							
Sport	[illegible]	[illegible]							
Passenger Van	[illegible]	[illegible]							
Intermediate	[illegible]	[illegible]							
Regular	[illegible]	[illegible]							
High	[illegible]	[illegible]							
Imports	[illegible]	[illegible]							
Grand Total	100.0	100.0							

* Excluding Checker.

SOURCE: Compiled by Statistics Department, Motor Vehicle Manufacturers Association of the U.S., Inc. March 18, 1975

APPENDIX C

AUTOMOTIVE USE OF PLASTICS AND RECYCLING POSSIBILITIES

by C. Weaver

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AUTOMOTIVE USE OF PLASTICS AND RECYCLING POSSIBILITIES

C.1 PLASTICS TECHNOLOGY

Over 3,000 of the 13,000 parts in the average car are made of plastic. Most, of course, are very small, and a majority are welded to or connected with a variety of nonplastic materials. The finished plastic part is specific to its end use and to that use only; it is intended to perform one function for a number of years, and when it ceases to function, it becomes waste, a form of waste peculiarly difficult to reuse, segregate or dispose of economically.

The plastics used in cars are heterogenous in size, shape, connection with other components and, most pertinently, in the compositions of the resin itself. The material's greatest asset and worst recycling stumbling block is its enormous variety. Within the family of polyethylene alone, for instance, there are over seven hundred different grades. The initial variation in resin type is further compounded by the ubiquitous use of additives for filling, reinforcement and coloring. The final plastic part is almost as individual as a snowflake; more so when one considers that snowflakes are reasonably homogenous in composition.

Table C1 lists the six major families of plastics and their basic constituents. Most plastics start with the production of ethylene from oil refinery byproducts or from natural gas purification plant products. The ethylene is then combined with other chemicals. In the following diagram the arrows show the steps from ethylene to the three major plastics.

Polymerized Ethylene → Polyethylene
Ethylene + Chlorine → Vinyl Chloride Monomer → Polyvinyl Chloride
Ethylene + Benzene → Styrene Monomer → Polystyrene

Plastics are made up of chain-like molecules of high molecular weight. Simpler molecules, called monomers, provide the base for the synthesis of the extremely large molecules that are polymers. Each type of plastic calls for a different combination of monomers, the number of which can range from a few thousand to a hundred thousand repeating monomer units.

The gaseous molecule ethylene has no strength because the molecules are easily separated. When covalent bonds are established between the former

TABLE C1

MAJOR PLASTICS

Polyvinyl Chloride	(PVC)
Polyethylene	(PE)
Polypropylene	(PP)
Polystyrene	(PS)
Polyurethane	
Phenolics	

MAJOR CHEMICALS USED IN PLASTICS PRODUCTION

Vinyl Chloride
Ethylene
Propylene
Styrene
Butadiene
Acrylonitrile

ethylene molecules, the result is a polymer so strong in its high density form that Volkswagen has made a gas tank of it. The difference is simply that the molecules in the polymer are close and almost welded together by the strong forces between them.

Plastic is made of materials with varying melting points and properties. Thus, two polyethylenes will have different melting points based on differences in molecular weight distribution, distribution of molecules of different chain lengths, and the shape of the molecule - whether linear, branched, extensively branched or crosslinked. The former two configurations make up the "theromoplastics" which can be repeatedly resoftened and reformed. The best known polymers of this group are polyethylene, polystyrene, polyvinyl chloride, polypropylene and ABS (acrylonitrile-butadiene-styrene). Thermosets, which account for the balance of the production, are either extensively branched or crosslinked. They cannot be resoftened after the initial heating cycle. Typical among thermosets are the phenolics, epoxies and urea formaldehyde.

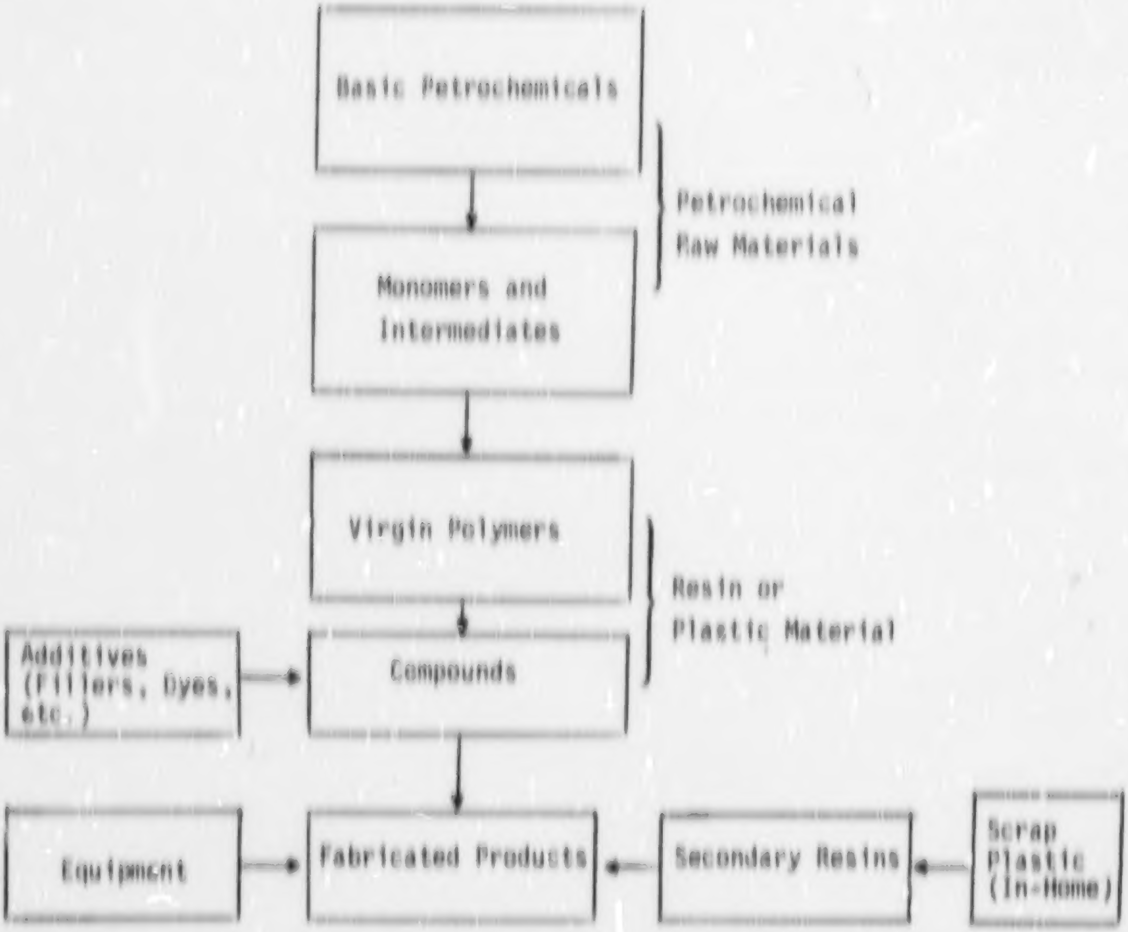
The transformation of a plastic to a useful item consists of three broad steps:

1. Compounding - the polymer is mixed with additives and colorants.
2. Fabricating - the resulting compounded or uncompounded polymer is transformed to a finished or semifinished product.
3. Connecting - the product is modified by decorating, sealing and/or cutting.

Figure C1 diagrams the structure of the plastic industry. Plastics currently represent about 150 pounds in the average full size automobile. Their use is increasing as engineers test their viability for structural and under-the-hood components. The plastic fuel tank developed by Volkswagen is paradigmatic of a developing technology. Made of a rugged, shock resistant high density polyethylene, the tank weighs 8 pounds (3.5 kg), achieving a weight savings of 29% over a comparable steel tank, and having a capacity greater by 1.6 gallon. Although high density polyethylene is inferior to steel in permeability resistance, it is superior in strength (per pound) and flexibility even at temperatures as low as -40°F. The

FIGURE C1

STRUCTURE OF THE PLASTIC INDUSTRY


Basic Petrochemicals
Petrochemical Raw Materials
Monomers and Intermediates
Virgin Polymers
Resin or Plastic Material
Additives (Fillers, Dyes, etc.)
Compounds
Equipment
Fabricated Products
Secondary Resins
Scrap Plastic (In-Home)

material is easily blowmolded and welded and the scrap generated by the process is 100% recyclable. Other under-the-hood parts now being made of plastics are fan blades, shrouds, and air filter covers, to name but a few.

The use of plastics for auto bodies is the center of much materials experimentation. The best known example of such use is Chevrolet's Corvette which has a body molded entirely of fiberglass reinforced plastic. Chevrolet has also developed the prototypical XP-898, a 2285 pound automobile with a unitized body chassis structure featuring a sandwich core of urethane foam covered by glass fiber reinforced plastic. Discreet internal ribs are not used; rather the principal is that of a "stressed skin" or monocoque construction. Citroen has also experimented with auto bodies made of plastic and has built one formed of thermoplastic ABS.

Plastic hoods and roofs are also on the increase. The roof of Toyota's Land Cruiser is made of fiber reinforced plastic; the front hoods of 1974 Mustangs, Pontiacs, Firebirds and Javelins are all formed of glass fiber reinforced polymer. The weight savings is significant. An auto hood made of steel weighs 75 pounds, while a one piece plastic hood is only 37 pounds.

Soft body parts - filler panels, fender extensions, and fascia - are currently produced by reaction injection molding of urethane components. Two high pressure streams of reactants are mixed by impingement as a very fast chemical reaction forms the solid part within the mold. Other processes include blowmolding, injection moldings, liquid molding and rotational power molding.

The potential for plastic rub strips, bump strips and flexible front and rear end panels is also good.

Bumpers made of plastic fulfill the two major requirements of support and energy absorbency. Fender liners are designed with either structural considerations in mind, in which case the material used is glass fiber reinforced plastic; or without this requirement, in which case they are made of unreinforced polypropylene.

Plastics have already replaced other materials for decorative and/or nonstructural components. Zinc diecastings are increasingly replaced by molded, reinforced plastics. A 1973 Pontiac side window louvre weighing about 20 pounds was replaced by an injection molded fiberglass reinforced thermoplastic polyester weighing less than 5 pounds. Plastics have also usurped the place of zinc die castings for trim, grilles, handles and decoration.

Experience in making large automotive parts of plastic is still lacking. One possibility is the use of equipment now employed in metal stamping for thermoplastic stamping.

C.2 PLASTICS USED IN AUTOMOTIVE APPLICATIONS

Thermoplastic elastomers, of which olefinics, saturated styrene block copolymers, polyethylene graft, copolyester and thermoplastic urethane are major examples, are catching on for exterior automotive trim, bumper systems and other flexible parts.

Sometimes called "elastoplastics," thermoplastic elastomers retain an elastomer's structural and recovery characteristics. They use a thermally reversible substitute for covalent crosslinks. Their structure usually consists of molecular chains with dissimilar and incompatible "soft" and "hard" links. The former are flexible, amorphous and elastomeric in character; the latter are stiff, glass or crystalline and have a relatively high Tg, (glass transition temperature).

At use temperatures, the hard segments are associated with each other in clusters. As temperature is increased, these "pseudo-crosslinks" soften or melt, permitting the plastic to be molded like an ordinary thermoplastic.

Although they are not naturally so, thermoplastic elastomers can be made more flame resistant. A major demand for under-the-hood use is that materials demonstrate a long term resistance to oil and heat. Elastic copolymers have both these properties and can be used for hose and tubing.

All thermoplastic elastomers are either candidates for or are already in use for light shields. They cannot yet be used for fascia.

Of this group, thermoplastic urethane, vinyl and thermoset EDPM share

the major uses today, while the major types of all plastics used automotively are polyvinyl chloride, polyurethane, polyethylene, ABS, and fiberglass reinforced plastics. These constitute over 80% of the polymers now used in automobiles. EDPM is expected to continue at its present high level through 1980 while others, such as PE, PVC, and PP may increase by as much as 50%. A continuing dominance may be expected by these three and ABS. A recent Business International Study showed that the most recent increases in automotive plastics have been in the proliferati
for platable ABS, high impact polypropylene and low shrinkage sheet molding compound (SMC).

Polyvinyl chloride, one of the most used polymers in cars, accounts for 30-40 pounds in the average GM car. It should be noted that new Government health and pollution standards on the production of PVC may shrink its availability to the point where substitutes will have to be found. General Motors has concluded that only two materials, chlorinated polyethylene and ionomer, approach PVC in cost and ease of substitution. These two materials themselves, however, are not readily available.

Although automotive use of plastics accounts for only 5% of total plastic consumption, some individual plastics are much more dependent on the transportation market. One third of the demand for PVC, for instance, is in automotive upholstery; 1/6 of the flexible foam produced is used by transportation.

Tables C2 through C4 and Figure C2 detail typical automotive uses of plastics. Table C4 contains an estimate by R. G. Garlund of the amounts of various kinds of polymers found in the average 1974 automobile, and an estimate by Modern Plastics Journal of the amounts of different plastics bought by the automotive industry for passenger cars in 1974. Disparities between the two calculations are probably due to two factors: the differences in definition and grouping of plastics; and the variance between the amount bought by the automotive industry and the amount actually present in the finished cars.

Unfortunately, there is no way of breaking down a car by the polymer used for each part. Different companies use different plastics for the same part. Even within a company, plastics used for the same purpose on

TABLE E2 PLASTICS Form Cond. Mfgr. Code

[illegible]

TOTAL PLASTICS 100 100.00

Manufacturer

00	Unknown
01	Saginaw
02	Torrington
03	Delco Products
04	Trico
05	Chevrolet
06	Delco-Morraine
07	Fisher Body
08	Delco Remy-Anderson
09	General Safety
10	Harrison
11	Inland
12	AC Spark
13	Delco-Remy
14	Eaton
15	Bundy
16	Hydra Matic
17	Automatic Radio
18	Packard Electric
19	General Electric
20	Guide Lamp
21	Frigidaire
23	Fabco
24	Morse (B-W)

Form

01	Fasteners
02	Castings
03	Forging
04	Bar
05	Sheet
06	Wire
07	Powder metal
10	Tubing
11	Plate
12	Rod

Condition

01	Machined
02	Drawn
03	Blanked or Stamps
04	Headed
05	Roll formed
06	Injection molded
07	Hot formed
08	Die cast
09	Soldered
10	Plated
11	Slit
12	Comp. Molded
13	Extruded
14	Foamed
15	Blow molded

00 = Unknown or not applicable

Source: Armco Report (7)

TABLE C3

AUTOMOTIVE USES OF PLASTICS

EXTERIOR

- Trunk lids
- Fender extension (nylon or unsaturated polyester)
- Grilles, painted and chrome plated (ABS: outside)
- Fender aprons (PP or PE)
- Lenses, lamp
- Lamp housings (rear, PP)
- Bumper sight shield (urethane or ethylene-propylene-copolymer)
- Bodies
- Safety glass
- Tire cords
- Front end (fiber glass or unsaturated polyester)
- Wheel covers (ABS or polyphenylene oxide)
- Fender liners; wheel wells (unreinforced PP or fiberglass reinforced plastic)
- Clips
- Hoods
- Rub strips (PVC)
- Bump strips
- Bumpers
- Soft body parts
- Vinyl tops
- Flexible front and rear panels (PP or thermoplastic methanes or vinyls)
- Fuscia
- Filler panels
- Seals

UNDER THE HOOD

- Canister for emission controls
- Windshield washer reservoirs
- Filler tubes
- Brake fluid containers
- Filter neck housings
- Horn shrouds

TABLE 63

(CONTINUED)

- Oil reservoirs
- Gaskets (urethane foam)
- Carburetor air filters (urethane foam)
- Fuel tank (PE or nylon)
- Fuel tank baffling
- Battery case
- Wiring insulation
- Fan shrouds
- Fan blades
- Fan housing
- Ducts
- Small gears (e.g., speedometer of nylon)
- Bushings
- Tubings
- Electrical and wiring (phenolic, PVC or PE)
- Air filter covers
- Knob wiring harnesses
- Radiator grilles and cabinets (ABS)
- Carburetor spacers (nylon)
- Distributor covers (nylon)

INTERIOR

- Seats (rigid thermoplastic foam)
- Seat track stops (molded nylon)
- Sun visors (PVC)
- Padded rear view mirror (PVC)
- Upholstery covers (PVC or nylon)
- Upholstery padding (urethane foam or PVC foam)
- Carpet underlay
- Carpet (PVC or nylon)
- Thermal insulation (urethane form)
- Acoustical insulation (urethane foam)
- Arm rests

TABLE C3

(CONTINUED)

- Window regulator rollers (nylon)
- Steering column (acetal)
- Seat belts (nylon)
- Dashboards
- Instrument cluster assemblies (fiberglass reinforced PS)
- Steering wheel (cellulosic, PVC)
- Door panel coverings
- Extruded items (e.g., interior trim)
- Accelerator pedal (polypropylene)
- Headrest (urethane, PVC)
- Instruments
- Ignition parts
- Styled roof (PVC)
- Heater housing (unsaturated polyester)
- Air conditioner housing (unsaturated polyester)
- Crash pad retainer (fiberglass reinforced PS)
- Trim (glovebox: PP, PVC, ABS)
- Cowl kick panels
- Handles
- Decoration
- Air conditioner parts (polycarbonate)
- Crash pads (ABS, PVC or Urethane)
- Molded components
- Headliners

ABS = Acrylonitrile-Butadiene-Styrene
PVC = Polyvinyl Chloride
PE = Polyethylene
PP = Polypropylene
PS = Polystyrene

Sources: 1. Roy Renner, Appendix A.
2. Markets for Plastics, 1969 Reinhold Corporation, New York

TABLE C4

ESTIMATES OF AUTOMOTIVE PLASTICS

TYPE	GARLUND POUNDS PER CAR	GARLUND PERCENT	MODERN PLASTICS METRIC TONS PER YEAR	MODERN PLASTICS PERCENT
Polyurethane	35	23.4	123.0 (a)	21.6
Polyvinylchloride	30	20.1	110.0 (b)	19.4
Polypropylene	22	14.7	90.0	15.8
ABS	15	10.1	10.9	62.0
Polyester	10	6.7	68.0 (Reinforced Polyester)	12.0
Polyethylene	6	4.0	22.0 (HD + LD)	3.9
Polyamide (Nylon)	6	4.0	14.8	2.6
Phenolic	5	3.4	23.0	4.1
Acrylics	3	2.0	14.4	2.5
Polystyrene	2	1.3	3.0	.5
Acetyl, Polyacetyl	2	1.3	5.7 (Polyacetyl)	1.0
SAN	1	.7	4.5	.8
Other	12 (c)	8.1	26.4 (d)	4.6
	149	99.8	567.5	99.9

Average difference between estimates - 1.3%.

(a) Includes urethane foam crash padding, upholstery, high density micro-cellular bumper materials, rigid foams and thermoplastic urethane.

(b) Includes calendared upholstery, vinyls, extruded flexible materials and semi-rigid compounds.

(c) Includes cellulosics, alkyds, epoxies, polycarbonates.

(d) Includes "other", cellulosics, polycarbonates.

Sources: R. G. Garlund in Roy Renner, Appendix A.
Modern Plastics Journal, January 1974.

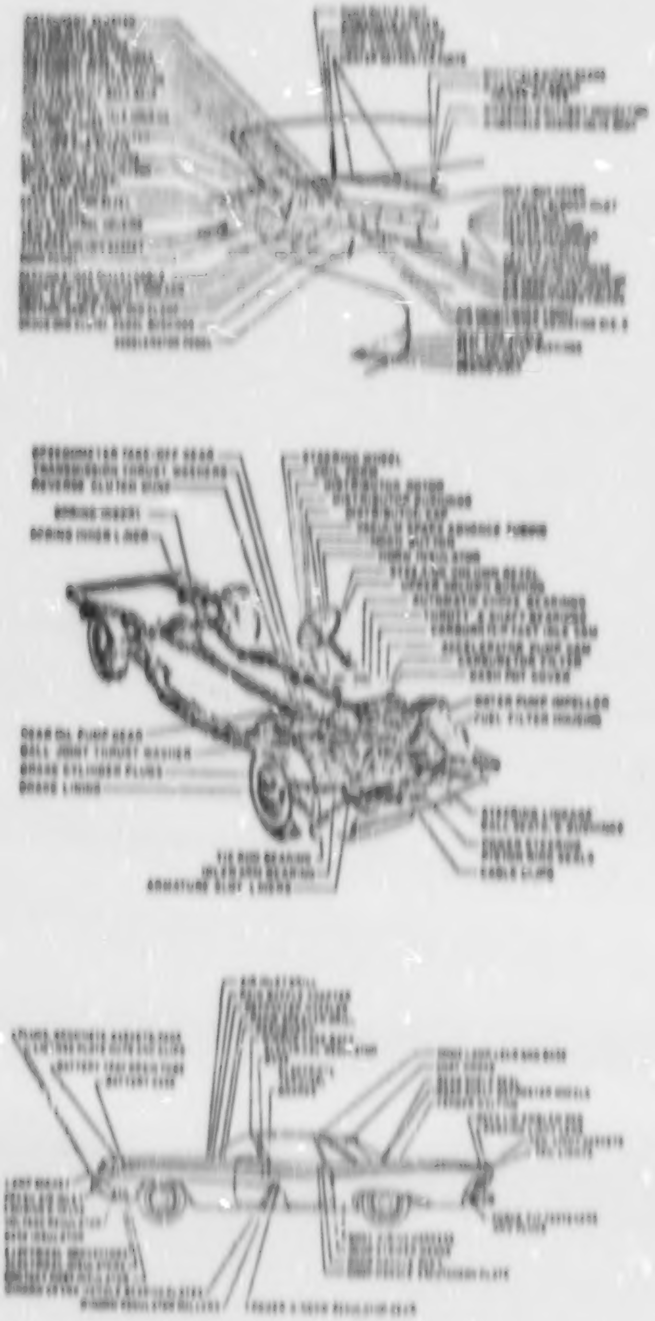

SPEEDOMETER TAKE-OFF GEAR
TRANSMISSION THRUST WASHERS
REVERSE CLUTCH DISC
SPRING INSERT
STEERING WHEEL
DASH POT COVER
WATER PUMP IMPELLER
FUEL FILTER HOUSING
GEAR OIL PUMP GEAR
BALL JOINT THRUST WASHER
BRAKE CYLINDER PLUGS
BRAKE LINING
CABLE CLIPS
ARMATURE SLOT LINERS

Figure C2. Plastic Components of Automobiles

Source: Markets for Plastics 1969, Reinhold Corporation, N.Y.

different automotive lines may not be of the same type. Table C3 illustrates some of the possibilities.

C.3 EXPECTED IMPROVEMENTS IN PLASTICS BY 1995 (2), (3)

1. High temperature capability of plastics will improve to about 700°F., (370°C) for continuous applications. This will allow the plastics to cope with the higher temperatures under the engine hoods. The industry is already constructing polybutylene, tetraphthalates, and polyamides. Recently, a copolyester resin capable of resisting 370°C. (700°F) and suitable for injection mold has been announced.

2. Considerable improvement will take place in the manufacturing and properties of fiber glass reinforced plastics leading to improved dimensional stability and easier processing. A recently announced new glass fiber roving eliminates fiber visibility in the finished plastic product.

3. Continuous advances will be made in the area of "self-skinning" urethane foam sandwich body bands and rigid urethane foam skin composites.

4. Plastics with much better resistance to weathering and fire will be available by 1995. The automotive plastic industry will benefit from the research investments of the construction industry in this area.

5. Polymer engineering will emerge as a sophisticated, computerized technology designing new polymers to suit the requirements. Thermoplastics capable of reversible cross-linking will be developed. One type will be thermoplastic at machine temperatures, that will form cross-linked structural material at low temperatures. Another type would stiffen under stress like a muscle polymer.

C.4 FUTURE ADVANCES IN THE FABRICATION OF PLASTICS (3)

The following advances in the fabrication of automotive plastic parts will be more important in accelerating the use of plastics than the improvements in the properties of plastics themselves:

1. Huge injection presses of 5,000 to 10,000 ton clamp force, producing parts at very fast rates,will be available by 1995. There will be rapid growth in thermo-forming, rotational-molding, and increases in part sizes. Faster molding of thermo-setting plastics, including reinforced varieties via injection molding rather than compression molding, will be used more and more by 1995.

2. Blow-molding, for instance of gasoline tanks, will become more popular.

3. Cold-forming of plastics, such as cold stamping of complex parts, will become important due to their low-cost, high-fabrication rates, and availability of metal-forming equipment.

4. Direct conversion of newly made resin, or of monomers and prepolymers into final parts, using gamma ray and other sources of radiant energy for polymerization, could become a reality by 1995. This would cut down the costs tremendously, since these new techniques eliminate intermediate pelletization, storage, and transportation.

5. A variety of improvements in curing of plastics, including the use of radiation to reduce curing time may be expected. Certain companies are considering utilization of high-speed, electron-radiation curing of polymers, friction welding, and rapid-cure in sheet molding to make plastic fabrication competitive with metal forming.

6. Another possible advance is the strain-free injection molded parts derived from thermo-plastics with very low melt-viscosity. This has made possible fabrication of thin-wall, warp-free flat panels resembling the sheet metal or laminated paper they can replace.

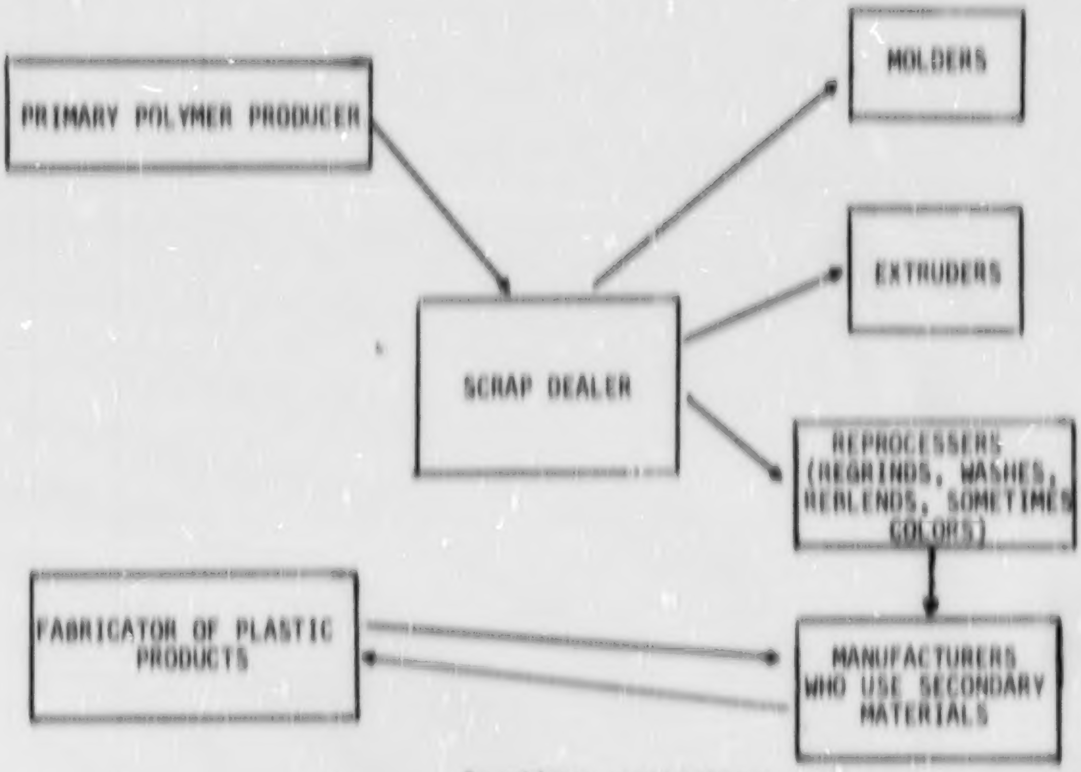
C.5 THE PLASTIC SCRAP INDUSTRY

It is common for thermoplastic wastes to be recycled at the plant fabrication stage. After molding or calendering, thermoplastic scrap and trimmings are mixed with new resin and reprocessed. Repeated softenings, however, harm the physical properties of the polymer. This is why scrap resulting from plastic originally slated for high quality products is often sold to manufacturers of less demanding products - toys, plastic flowers, etc. If the manufacturer is to remain in business, he must have a constant supply of the same type of scrap, since different grades cannot be mixed.

Manufacturers give precedence to virgin polymer because the uniformity of prompt scrap is so often questionable. The use of post consumer scrap is close to nil because the separation of plastics, first from other waste, then by color and resin type, is difficult and expensive. Figure C3 illustrates the structure of the plastic scrap industry.

FIGURE C3

THE PLASTIC SCRAP INDUSTRY


PRIMARY POLYMER PRODUCER
MOLDERS
EXTRUDERS
SCRAP DEALER
REPROCESSERS (REGRINDS, WASHES, REBLENDS, SOMETIMES COLORS)
FABRICATOR OF PLASTIC PRODUCTS
MANUFACTURERS WHO USE SECONDARY MATERIALS

Sometimes reprocessers operate contractually with fabricators

Some of the obstacles encountered in plastics recycling are listed below:

1. Degradation of resin properties occurs during the first manufacture, from aging, and from the reclamation process.

2. The technology for purifying and upgrading contaminated, colored and degraded plastics is generally lacking.

3. The cost of collecting and shipping plastics to points of reclamation are often prohibitive.

4. Effective market mechanisms for trade in reclaimed plastics have not been developed.

5. Standards for recycled plastics have not been developed.

6. Plastics users distrust the uniformity of reclaimed plastics and are hesitant to add another variable to a process already imprecise.

C.6 USE OF POST CONSUMER AUTOMOTIVE PLASTIC

The imperative for a sound post consumer treatment of automotive plastic waste is gaining urgency as plastic replaces automotive steel in increasingly large proportions. The inadequacies of the landfill - its lack of financial reward, waste of resources, both those buried and those burying; and its simple inappropriateness to certain kinds of plastics - have sparked investigation of other disposal options, the best of which seek to either recycle plastics or recover their stored energy.

Three broad possibilities exist for waste plastics. They may be:

1. Remelted, reprocessed and recycled as conventional plastic products. This involves hot extrusion and remolding of thermoplastics, and dissolution and reconstitution of thermosets.

2. Reused as substitutes for nonplastic products in building and in the production through pyrolysis of chemicals, fuels and soil mulch.

3. Burned in an unsorted form for energy reclamation.

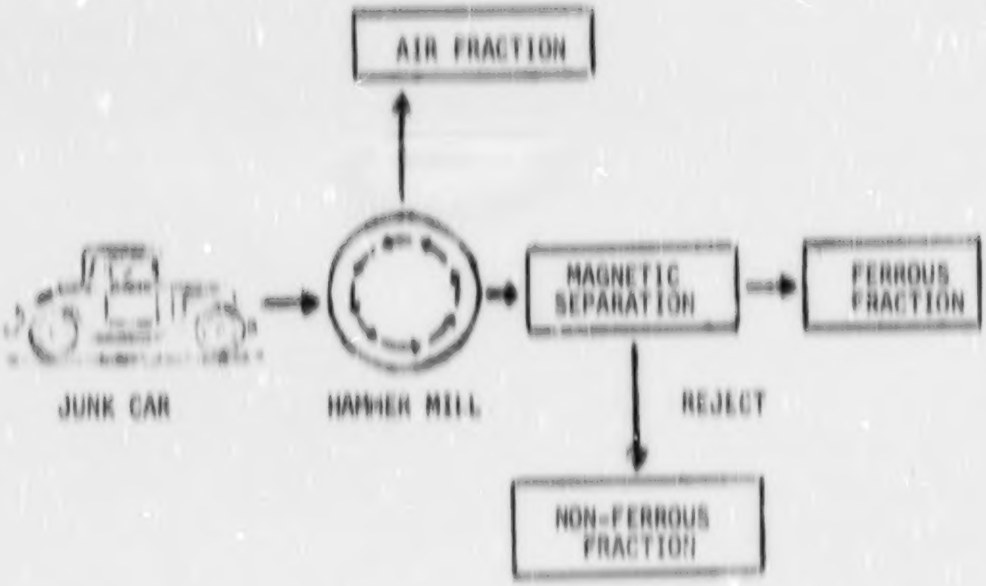
The plastic wastes in cars present a special problem for their heterogeneity is great, and because the car is essentially "speckled" with plastics. They are found everywhere in small applications. The use of plastics for large body parts will change this,of course, but the fact remains that plastics are scattered widely throughout the car, welded or attached to nonplastics, covering wires, containing equipment, sealed to the roof. Their removal by handstripping is obviously impracticable, with the exception, perhaps, of urethane foam seats; their segregation into types after shredding requires a more advanced technology than now exists, and may prove inordinately expensive.

The auto shredder, a relatively recent innovation, was developed in response to laws prohibiting open burning and to the cost of handstripping. Cars stripped of parts, gas tanks, and sometimes seats are fed into a hammermill (grinder) which shreds them into fist-size pieces of mostly steel material. The pieces (see Figure C4) are next passed through air knives which remove nonmetallic residue and then through magnetic separators which segregate ferrous from nonferrous material. The nonmetallic detritus is called the "air fraction" and consists of low density materials now used in landfill. J. S. Harwood, of Ford Motor Company, has estimated that, after 1975, million pound quantities of ABS, polypropylene, and polyurethane will be generated from an auto shredder processing 100,000 hulks per year: "Since polyurethane foam is not a desirable landfill material, it can present a serious disposal problem by the late 1970's. These considerations led to a cooperative Ford-Bureau of Mines program to explore methods for the recovery of these larger quantities of plastic materials. Early results indicated that the recovery of plastics from shredded cars is technically feasible." (4)

The experiments included a method for the fractionation of waste polyurethane foam into its individually recyclable constituents, diamines and polyethers. The two can be recombined to make new foam. The process is fairly simple: the foam is separated from the contents of an auto shredder, sealed in a container with a little water and heated. Within 15 minutes hydrolysis occurs, the hydrolyzate is distilled and the product obtained.

Ford predicts that the process will be profitable to auto shredders, since its cost is estimated at 15 cents a car, with a return of 50 cents. It is associated with no pollution and could help to eliminate the disposal problem created by an estimated 600 million pound production of polyurethane in 1975.

FIGURE C4


AIR FRACTION
JUNK CAR
HAMMER MILL
MAGNETIC SEPARATION
FERROUS FRACTION
REJECT
NON-FERROUS FRACTION

SCRAP FRACTIONATION IN VEHICLE SHREDDING OPERATIONS

Source: (4)

Another study (4) indicated that a fraction of automotive plastic waste rich in unfilled ABS can be remolded with properties comparable to those of virgin reground ABS (see Figure C5). With the addition of blending agents, the impact properties of the remolded scrap can be improved.

The separation of plastic wastes by type is difficult, although some progress has been made on the laboratory scale with various sink flotation schemes. (see Figures C6 and C7). Classification by these methods is impeded by the use of additives in plastics which charge the weight and obscure a polymer's identity.

Other techniques tested by the U. S. Bureau of Mines for segregation of polymer types have been feel , sound, appearance, odor, gas chromatography, flame behavior and infrared spectroscopy. None have proved practicable on any but a laboratory scale.

The air fraction of a shredder's output includes not only plastics but dirt, glass, cotton and other light materials. Processes for separating these from resin have been designed with some success. The Bureau of Mines has developed a pilot system capable of separating plastics from mixed waste with a minor 1-2% contamination level. The technique breaks up and separates combustibles from noncombustibles through flailing and screening. Air classification leaves a mixture composed of plastics and paper only. Any remaining moisture is removed through conditioning and paper is separated from plastics with an electrostatic device.

The Cumberland Engineering Company has designed a vacuum gravity separator process primarily applicable to metals, but easily convertible to plastic wastes. Unsorted wastes are broken and shredded on a conveyor belt before passing beneath a cross belt magnet which attracts the ferrous metals. A three stage aspirator separates out light materials while the remainder is broken into smaller bits and relieved of nonferrous metals. Final screening and gravity separation produces fairly homogenous outputs of metals, glass and sand, compost and plastics. The process is in the design stage.

At least two machines have had some success in the recycling of scrap plastic.

INJECTION MOLDED ABS

	Reclaimed Shredder Scrap*	Virgin Grade	Virgin Reground	Virgin Reground & Blended
Tensile Strength - (PSI)	6300	5500 Min.	5500	5500
Flexural Yield Strength - (PSI)	8500	9000	9000	9000
Izod Impact Strength (Ft.-L.B./In. of Notch)	1.5	2.0-2.5	2.0	3.0

*Separated by density methods from the air fraction obtained from shredding a single 1972 Montego Two-Door T. T. Hardtop Sedan. The 16 lbs. with specific gravity between 1.0 and 1.075 contained 15.3 pounds of unfilled ABS.

Figure C5. Comparative Properties of Reclaimed Shredded Scrap and Virgin Reground ABS (4)

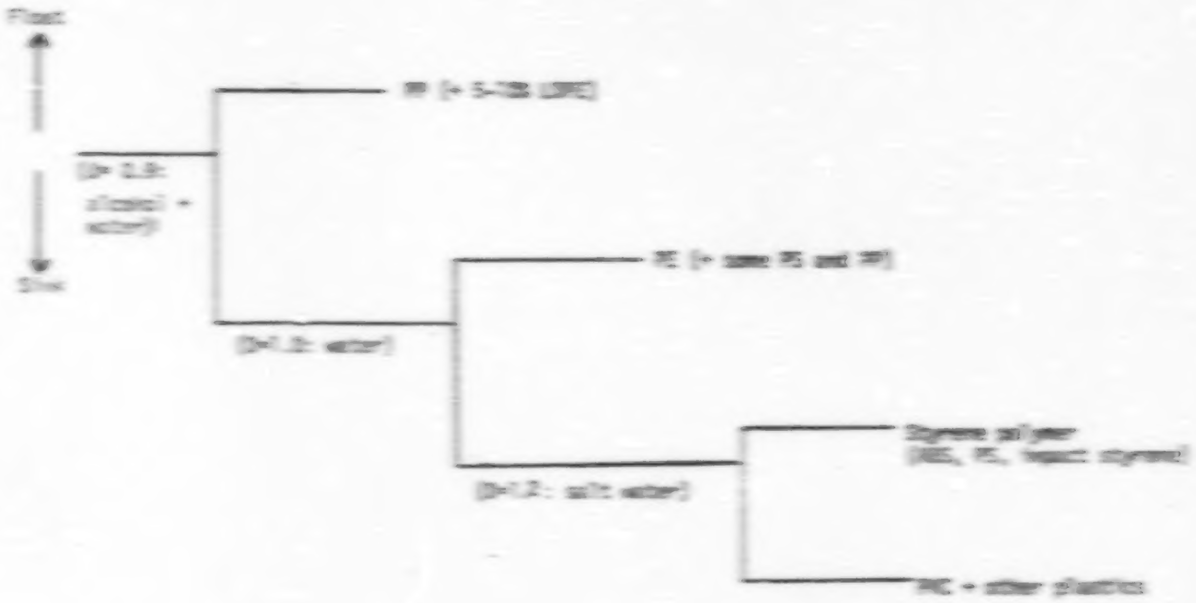
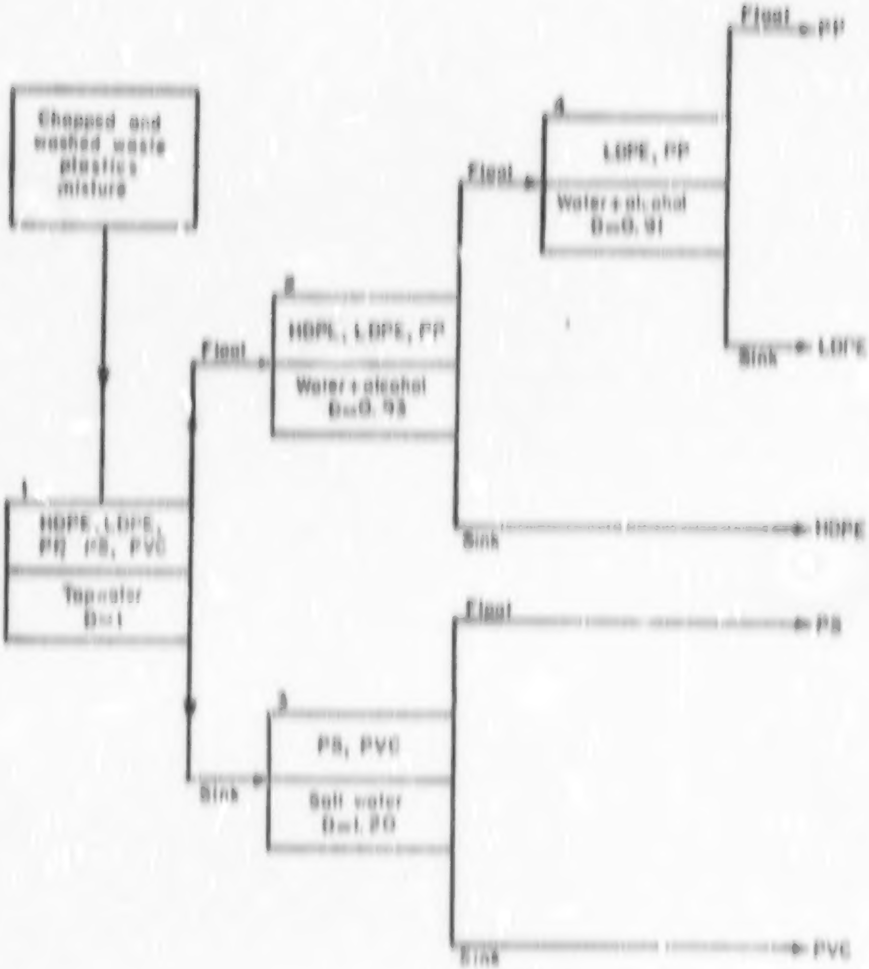

Float
Sink
(D= 0.9: alcohol + water)
PP (+ 5-10% LDPE)
(D=1.0: water)
PE (+ some PS and PP)
(D=1.2: salt water)
Styrene polymer
(ABS, PS, impact styrene)
PVC + other plastics

Figure C6. Separation of Plastics by
Polymer Type



Chopped and washed waste plastics mixture
1
HDPE, LDPE, PP, PS, PVC
Tap water D=1
Float
2
HDPE, LDPE, PP
Water + alcohol D=0.93
Float
4
LDPE, PP
Water + alcohol D=0.91
Float
PP
Sink
LDPE
Sink
HDPE
Sink
3
PS, PVC
Salt water D=1.20
Float
PS
Sink
PVC

Figure C7. Theoretical Four Stage Sink Float Scheme for Separating Waste Plastic Mixture (5)

The Vertruder, designed by the Gloucester Engineering Company, is a vertical extruder preceded by a grinder which chops the scrap into manageable pieces. The material is carried by a blower into a hopper and auger where the plastic is melted and extruded through a screen pack and strand die into a water trough. The plastic strands are passed through an air stripper or dyer and pelletized. (see Figure C8)

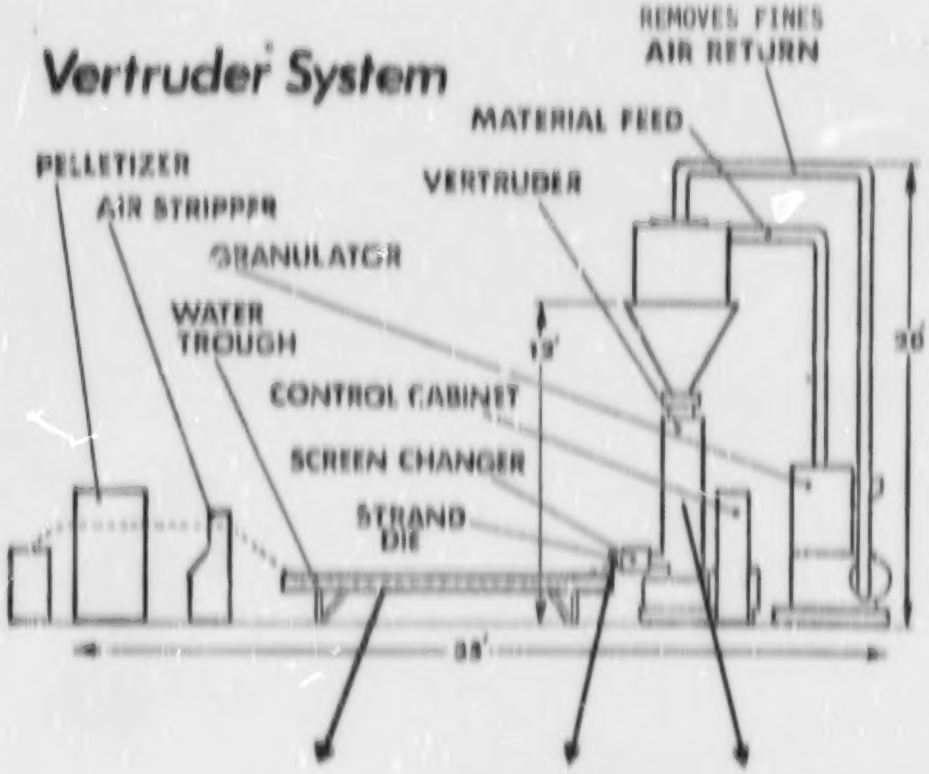
The major problems encountered in this process are contamination, whether from nonplastic impurities or different plastics. If thermosetting plastics are present in the load, they will pack in the extruder screen, blocking the flow of thermoplastics and eventually causing an explosion if pressure sensors are not used. The same danger is present when thermoplastics of different melt temperatures are combined. Plastics of low melt temperature may vaporize and act as gaseous fillers in extruding plastic, causing serious defects. The quality of reprocessed plastic is further compromised by the presence of wood, paper, dirt and fines.

The "Remaker," a German-made machine, has overcome these problems. The machine injection molds a diverse line of plastic products using an almost unlimited mix of thermoplastic scrap. No virgin plastic at all is required and different thermoplastics may be combined, although the composition must be known beforehand so that the machine may be adjusted. No prior processing of the plastic is necessary and variations in the product are decreased by the addition of inexpensive pigments and plasticizers. The Remaker molds products of up to 55 pounds, typical among which are shoe soles, luggage handles, suction pumps, seals, bike saddles and pedals, lawnmower wheels and auto parts.

It is sometimes claimed that the energy value inherent in petroleum is not lost but merely stored when petroleum is used to make plastics. This is not entirely true. There is an amount of energy used in the production of resin which exceeds that energy stored in plastics and is clearly irrecoverable. The real question is how much energy is potentially retrievable.

FIGURE C8

VERTRUDER SYSTEM FOR RECYCLING SCRAP PLASTIC


Vertruder System
REMOVES FINES
AIR RETURN
MATERIAL FEED
PELLETIZER
AIR STRIPPER
VERTRUDER
GRANULATOR
WATER TROUGH
CONTROL CABINET
SCREEN CHANGER
STRAND DIE
19'
26'
38'

Water Trough Temperature 90° F.

Extrusion Through Screen

Here Plastic is Melted. Temperature c. 300°F.

Using Garlund's estimation of the weights of different plastics in the typical 1974 automobile, an idea of the inherent energy content of automobile plastics can be derived. In Table C6, the number of pounds assigned to the different plastics are multiplied by the BTU values associated with them. An average BTU/pound value of 16,000 is used as a factor when that of the particular plastic is unknown. Garlund's estimate is close to identical (149 as compared with 150) to Renner's Car A, and has been assumed to be the same.

Pyrolysis, sometimes called destructive distillation, is the thermal breakdown of waste in the absence of oxygen. Organic matter such as plastics and paper decomposes and is recovered by the distillation of separate gaseous, liquid and solid fractions. Typical products are urethane, methanol, fuel oils and inorganics (see Figure C9). Volatile components are driven off by the process leaving a residue consisting of carbon and ash. The proportions of liquid or gaseous products driven off may be varied by changing the temperature and pressure.

Although capital and operating costs are higher for pyrolysis than for incineration, the process yields more valuable and easily marketed products. It is especially applicable to the plastics problem because disposal is complete, air pollution nonexistent, and large scale conservation of natural resources is achieved.

The Union Carbide Company uses pyrolysis in the production of low molecular weight polymers, waxes, greases, oils, and gas from all the major plastics. Their efforts have especially concentrated on polyethylene, polystyrene and polyvinyl chloride. The waxes may be used in the production of paste polishes, printing inks, lubricants for high polymers and release agents for rubber tires. They may also be emulsified and used in textile softening agents and adhesives.

In the pyrolysis of PS, recovery of the styrene monomer appears possible. In that of PVC, the resulting HCL must be neutralized or vented through a scrubber. The Union Carbide Company has also tried pyrolisis of unsorted plastic wastes. The product is a high molecular weight oil, valuable as a binder in asphalt, as an agricultural mulch, or as a fuel.

TABLE C5

BTU VALUES FOR THE PLASTIC PORTIONS OF TYPICAL 1974 AUTOMOBILES

TYPE	lbs/CAR (CAR A)	BTU/lb*
ABS	15	@ (16,000)
POLYESTER	10	@ (16,000)
NYLON	6	@ (16,000)
HDPE, LDPE	(6) 3 3	 @ 20,100 @ 18,700
ACETAL, POLYACETAL	2	@ (16,000)
ACRYLIC	3	@ (16,000)
PHENOLIC	5	@ (16,000)
POLYPROPYLENE	22	@ 20,000
POLYSTYRENE	2	@ 17,900
POLYVINYL CHLORIDE	30	@ 7,720
POLYURETHANE	35	@ (16,000)
SAN	1	@ (16,000)
OTHER	12	@ (16,000)

Car A Total BTU Value = 2,247,800

Car B " " " = 1,600,000 (est.)

Car C " " " = 1,150,000 (est.)

Composite " " = 1,800,000 (est.)

*Value in () is the average for all plastics. It is used where actual values were not obtainable.

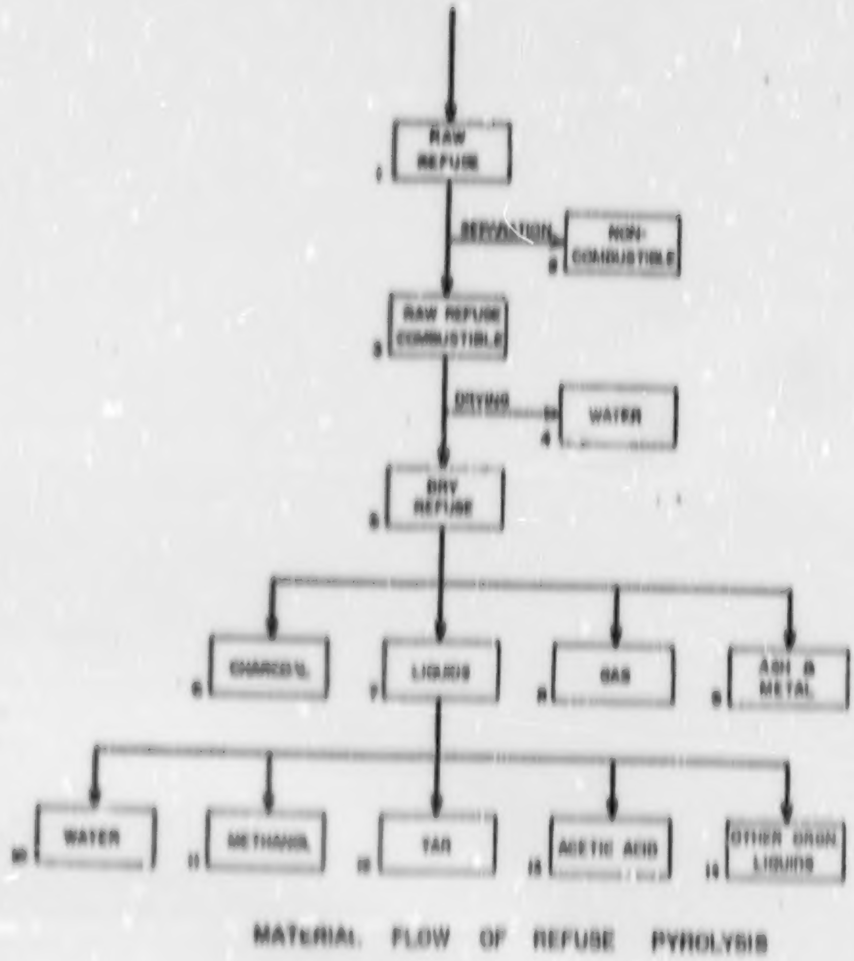

RAW REFUSE
1
SEPARATION
NON-COMBUSTIBLE
2
RAW REFUSE COMBUSTIBLE
3
DRYING
WATER
4
DRY REFUSE
5
CHARCOAL
6
LIQUIDS
7
GAS
8
ASH & METAL
9
WATER
10
METHANOL
11
TAR
12
ACETIC ACID
13
OTHER ORGN LIQUIDS
14
MATERIAL FLOW OF REFUSE PYROLYSIS

Figure C9. General Flow Sheet for Refuse Pyrolysis (6)

Pyrolysis has been in use for many years in the production of methanol, acetic acids, and turpentine from wood, with the recovery of the residual charcoal. The promise of pyrolysis is the production of simple organic molecules from materials ordinarily buried or incinerated. These simple organic molecules will serve as the building blocks for the synthesis of polymers and other petrochemical products.

C.7 INCINERATION OF PLASTICS WITH HEAT RECOVERY

New municipal incinerators are built to operate 24 hours a day with continuous feeding. The older, batch-fed incinerators are being gradually discarded because of their erratic temperature changes and inefficient smoke controls.

Plastics raise the heat value of combusted wastes. Mixed refuse has a value of only 4,500 BTUs per pound; plastics, in comparison, average at 16,000 BTUs per pound.

Incineration of plastics produces only small amounts of ash, ranging from .47% for polystyrene to 4.3% for polyurethane. Study of the emissions produced by burning resins found no significant increase in smoke, while plastic free waste seems to produce about the same amount of HCL as does refuse containing plastics. The amount of sulfur oxide produced by incineration of plastics is negligible.

Municipal incinerators produce, but do not use, a great deal of energy. This energy could be recovered in the forms of:

1. Steam for Electrical Generation

There are two ways to generate electricity from refuse: steam may be produced through a heat exchanger using waste heat from combustion, or waste combustion gases may be used directly to power a gas turbine. The latter method produces power for internal plant needs with the excess sold to utilities or other industrial users. The operation is not intended to be profit making; the sale of electricity is secondary, the primary purpose being waste management.

2. Steam

Steam produced by the burning of refuse may be sold to an electric utility or to any facility using steam for space heating. The incinerator used is a conventional municipal unit with an add-on heat recovery system. Steam is generated either by using waste-heat boilers in a refractory furnace or by using water-walled furnaces for better heat-transfer efficiency.

Although new incinerators in the U. S. come equipped with heat exchangers, the conversion of older incinerators to heat recovery is not terribly difficult.

A third option for the thermal disposal of plastic wastes is to use them as supplementary fuels in combination with more conventional fuels such as coal. This solution has several advantages over incineration:

1. Existing equipment is used, including that for ash disposal.
2. Coal is saved in proportion to its replacement by waste.
3. The market is already in place.
4. Costs of waste management may be saved.

The use of incineration with heat recovery will remain the most expeditious and inexpensive option for waste management for some time. Although pyrolysis may be an equally attractive solution, the installation of pyrolysis systems throughout the country is doubtful, while the practice of incinerating municipal wastes is extremely widespread. Heat recovery in incineration plants is more the exception than the rule. As it becomes more commonplace, the plastics component of waste will become more desirable and cities may relieve auto shredders of their air fraction wastes, instead of requiring them to dispose of them privately. The energy in used automotive plastics will be recovered in some measure by combustion, until more sophisticated recycling programs, standards and market mechanisms for dealing in secondary plastics are developed.

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APPENDIX D

SAFETY ASPECTS OF MATERIALS SUBSTITUTION

by R. Roig

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SAFETY ASPECTS OF MATERIALS SUBSTITUTION

D.1 Present Practices

Current safety standards issued by the National Highway Traffic Safety Administration (NHTSA) of the Department of Transportation (DOT) which could have a substantial impact on choice of materials used to manufacture automobiles include the following:[1]

No. 204	Steering Control Rearward Displacement
No. 205	Glazing Materials
No. 214	Side Door Strength
No. 215	Exterior Protection (bumper impacts)
No. 216	Roof Crush Resistance
No. 301	Fuel System Integrity
No. 302	Flamability of Interior Materials

As nearly as can be determined from current design practices, none of these standards (with the possible exception of No. 205) has inhibited manufacturers in their choice of materials. Manufacturers have been able to meet these standards using a variety of materials.

Standard No. 204 limits the rearward displacement of the steering column into the passenger compartment in the event of a frontal collision. Adherence to this design standard appears to be a matter of proper linkage design. While steel remains the dominant material in steering columns, no physical impediment to designs using aluminum exists.

Standard No. 215 requires passenger cars to withstand impacts of 5 mph and 2.5 mph in front and rear impacts, respectively, without damage to lighting, fuel, exhaust, cooling or latching systems. Passenger cars which meet this standard have bumpers made from either steel (most cars) or aluminum (e.g., Vega) and some 1975 Renault models have fiberglass reinforced plastic bumpers.

Standard No. 214 imposes crush resistant standards on side doors in an impact with a 12" diameter steel cylinder. While no production cars, tested to meet this standard, use aluminum for side door construction, a prututype aluminum body car was built by Reynolds Aluminum Co. for General Motors.[2] This body was built to meet identical specifications in terms of strength as a steel body of identical shape and size. While the aluminum body was apparently not subjected to impact tests, there is every reason to believe that it would perform as well as its steel counterpart. Corvette utilizes a fiberglass body construction but according to information from General Motors,* the crush resistance strength is obtained from steel reinforcing bars inside the door structure. In applications where crush resistance over substantial distances is important, it is likely that fiberglass reinforced plastics will require backing by steel or aluminum structure to provide elongation. Unreinforced elastomeric plastics can provide small crush resistance forces over appreciable distance and subsequent return to their original shape. However, it is unlikely that plastics without underlying metallic structure can be used to provide the substantial crush resistance forces (2250 lbs to 3000 lbs) required by Federal Standard No. 214.

Similar statements can be made in regard to Standards No. 216 (roof crush resistance) as for No. 214 above. Aluminum structure can be substituted for steel to meet the specification but plastic (fiberglass) body structure will require aluminum or steel reinforcing.

In Standard No. 301, the integrity and security of fuel tanks, filler pipes, and fuel tank connections are specified in terms of allowable fuel spillage (not to exceed one ounce per minute) following a 30 mph frontal barrier crash and subsequent rollover. Most tanks are currently made of a plated steel while Volkswagen has recently introduced a blow molded plastic tank (high-density polyethylene). No apparent obstacle, other than cost, exists to the use of aluminum for a gas tank (aircraft fual tanks are often made of aluminum). Probably the design and placement of fuel system parts, in terms of allowance for bending and stretching at joints, is at least as important as material composition. We conclude that there is no obstacle to substitution of either plastic or aluminum for fuel system components that are currently made of steel.

---

*Conversation with Mr. David Reed of GM Materials Division.

It should be noted in passing that, from a safety standpoint, gas tanks are a hazard in the recycling of cars. Shredder operators demand their removal because of the danger of explosions, and the act of removal is itself a moderately hazardous job that must be done outdoors. (In all the literature on automobile scrap reprocessing, not one word is found on what is done with all those gas tanks! We will discuss that matter in [illegible] paper on the shredder industry.)

The Standard on flamability of interior materials, No. 302, requires that the seat covers, padding, headliners, dashboard and other interior materials be "fire retardant." Most of these materials are already made of plastic or composites of plastics and fibers either natural or synthetic. All plastics will burn to some extent, being principally hydrocarbons. However, PVC, polycarbonates, and flurocarbon plastics tend to be inherently fire retardant because they release gases during thermal decomposition which tend to smother the flame.[3] Flame retardation in plastics is obtained or enhanced by using plasticizers or fillers such as certain phosphates, chlorinated synthetic polymerics, antimony oxide, and other compounds containing bromide, chlorine, antimony, and phosphorus. The principal implication for resource recovery is the resultant heterogeneity of the plastics used, making their reclamation for reuse much more difficult or perhaps even impossible. Fire retardant fillers also cause the plastics to be less valuable as fuels, because they are difficult to burn unless mixed with substantial quantities of higher quality fuels, and second because the fillers tend to form noxious gases or residues during burning. For instance, hydrochloric acid is among the combustion products of PVC and other chlorinated polymers. Hence the flue gases from PVC combustion would require scrubbing or other treatment prior to release to the atmosphere.[4]

The principle requirement of the Standard on glazing materials, No. 205, is that the windshield be constructed to preclude penetration by a passenger's head during a frontal collision. As a result windshields are universally constructed of a glass-plastic laminate. An all-plastic windshield is a future possibility, if an abrasion resistant surface can be imparted to a clear plastic. Otherwise, little change in glazing materials is likely in the foreseeable future.

D.2 Future Requirements

While the past several years have witnessed a rapid growth in the extent and severity of federally promulgated safety standards, there is no way to predict the trend of future activity in this area. It is quite conceivable that economic and energy policy considerations will override safety concerns and prevent imposition of more stringent safety standards, or even rollback present requirements. Added safety requirements usually mean additional car weight and cost, particularly requirements related to crashworthiness. Even now there is considerable agitation by car manufacturers to decrease the frontal impact speed requirement in Standard No. 215 (bumper impacts) to 2.5 mph from 5 mph, with cost and weight reduction as the motivation.

Without assigning any predictive value to the exercise, a perusal of the experimental safety vehicle (ESV) program[5,6,7,8] of the National Highway Traffic Safety Administration (NHTSA) will provide some insight into possible future safety standards and their influence on the choice of materials used in automobiles. Under this program four manufacturers were given contracts to design and fabricate four "family sedan" prototypes which met very severe safety standards. One aspect of safe vehicle design which the NHTSA program addressed[*] and which is of particular concern to the choice of materials for automobile construction was "crash energy management." The materials actually chosen by the four manufacturers in the construction of their ESV prototypes should give us some clue to possible future choices in vehicle manufacture, if stringent crashworthiness standards are ever promulgated.

The term "crash energy management" derives from the fact that in a collision with a fixed rigid barrier, the kinetic energy of the moving body, relative to the barrier, must be dissipated, appearing as thermal energy in deformed structure or in other places such as the hydraulic fluid forced from a stroking cylinder attached to a bumper. In collisions with a moving (or movable), and deformable barrier (i.e., another car), the concept is less clearly defined since the energy dissipation requirements depend on how kinetic energy is exchanged between the colliding bodies, and division of the energy dissipation between collision participants depends on detailed structural features peculiar to the participants. In any event the requirements in the NHTSA program were stated in terms of an allowable maximum deceleration of the passenger compartment vs. collision speed. The test conditions include numerous details[**] of speed and aspect to barriers and poles, but the most significant and stressing requirements which bear on materials selection were:

a.) for front or rear collisions at speeds up to 10 mph with a barrier or pole, no permanent[***] body damage and passenger compartment decelerations limited to 6 g's.[****]

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[*] Other areas, not particularly relevant to materials composition, were accident avoidance, post-crash safety, and nonoperating safety.

[**] See reference 5, pp. 5.3.2-6,7; 5.3.2-3; 5.3.4-3; 5.3.5-2.

[***] Crushed components, if any, return to original form.

[****] A "g" is 32.2 ft/sec^2--the gravity caused acceleration of a free falling body in a vacuum at the earth's surface.

b.) for front or rear collisions, with a barrier or pole, passenger compartment deceleration limited to 40 g's for collision speeds from 30 mph to 50 mph.

c.) for front, rear or side collisions, and rollovers, passenger compartment intrusion limited to 3 inches.

d.) no penetration of gas tanks, a release of fuel in collisions or turnovers.

(Other requirements related to passenger restraint and passenger decelerations are less relevent to materials substitution projections.)

The limitations on deceleration magnitude given above force a vehicle design which deforms in some manner on impact. To come to a stop from 10 mph without exceeding 6 g's requires that deceleration take place over a distance of at least 6.7 inches while the similar number for 50 mph and 40g's is 25 inches.* The distance between the bumper impact point and the passenger compartment frame must somehow decrease by this amount during the collision. Two design approaches to the problem evolved from the NHTSA program. The 10 mph (no body damage--6 g deceleration) impacts were absorbed by compressing hydraulic cylinders--any trim parts or front body pieces that would interfere with overall shortening of the forebody would either have to undergo a resilient deformation (e.g., a plastic elastomer could be used) or move rearward with the front bumper. (One vehicle manufacturer (GM) declined to meet the low speed impact criteria at 10 mph but designed to meet it at a 5mph collision where a 2.5 inch cylinder stroke is adequate. The reason given was the complexity required for the long stroke design.[8]) For the 50 mph impacts, the two manufacturers who were not primarily in the automobile business (AMF and Fairchild Industries) incorporated long stroke hydraulic cylinders. (In order to obtain the required stroke length, the bumper of the Fairchild Industries vehicle was extended forward when vehicle speed exceeded 30 mph. This allowed its car to survive the 50 mph collision with very little cosmetic damage to the front body.) The other two manufacturers (General Motors and Ford) used collapsing body structures to control deceleration and absorb the major portion of kinetic energy in the frontal collision; i.e., structural frame members were designed to bend and deform in a controlled manner during deceleration. (This results in substantial cosmetic and structural damage from a collision.) The Ford vehicle used corrugated frame rails designed to collapse at specific force loadings. The GM vehicle used a box frame with diagonal cross members designed to yield and collapse at specified load levels.

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*Actual designs must allow for substantially larger distances since a uniform deceleration is not practically attainable.

With either design philosophy, the amount of energy to be absorbed and the resistance force levels that have to be developed in a collision are directly proportional to the total mass that must be decelerated. Hence there is a very great incentive to keep weight in the vehicle body down to the lowest possible value. There is a compounding effect in that the weight of the energy absorbing system will be proportional to the deceleration forces required. It is interesting to note that in spite of these incentives all of the prototype cars built for the NHTSA program were very heavy vehicles, considerably heavier, in fact, than the project specification, which called for a 4000 lb. vehicle.[6] Weights ranged from about 6000 lbs for the AMF vehicle to about 5000 lbs for the GM vehicle.[5] (In fairness it should be noted the Ford vehicle used a modification of the production car body and engine, with little attention given to decreasing weight.[7] Also part of the relative lightness of the GM car can be attributed to their decision not to meet the no-damage criterion of a 10 mph barrier collision.[8])

During pole impacts, the bumper face bar is one of the most highly stressed members; it must withstand the full deceleration forces at its center of its own mass and half of the vehicle (less bumper) deceleration forces at each of two attachment points near the ends. The total load on the center of the bumper was calculated to be on the order of 400,000 lbs. by Fairchild.[6] Table D1 shows the materials choices and weights for the

TABLE D1

FRONT BUMPER BARS FOR ESV PROTOTYPES[5,6,7,8]

Manufacturer	Material Used	Weight, lbs
Fairchild Industries	High strength alloy steel	115
AMF	Aluminum alloy (7175-T66)	100
GM	Aluminum alloy (6061-T6)	108
Ford	High strength alloy steel (SAE4380-M)	90

bumper bar designs of each of the prototype cars. The interesting thing is that there appear to be no decided preference for steel or aluminum in this severe application - two manufacturers choosing aluminum and two steel - and the differences in weight of the bumper bars are also relatively small. It should be noted that the steel and aluminum alloys used in this application are tempered high strength varieties.

To understand the reason for this indifference to material choice, we need to look at the mechanical properties of aluminum and steel.[9] The ratio of the density of aluminum to that of steel is about 1/3. The yield strength of a high strength wrought aluminum alloy, properly tempered, can be as high as 80,000 psi, while the yield strength of high strength alloy steels can, with proper treatment, be brought to the range of 240 to 280 psi. Hence for equal weight of materials, the strength of the aluminum and steel bumper bars can be quite comparable. Or from another point of view, there is very little weight saving achievable from use of aluminum over steel in such a high strength application.

Of course high strength is not the only criterion of materials choice. Cost, formability, fatigue resistance, elasticity, weldability and corrosion resistance are other considerations. There are many applications in automobile design, other than the highly stressed parts, where the use of aluminum can effect a substantial weight savings. However, imposition of severe crash survival requirements on automobiles, if it ever occurs, will generate many requirements for high strength structural parts, and as illustrated by the bumper bar designs cited in Table D1, aluminum will not have a significant weight advantage over steel in these applications. Table D2 shows the physical properties of some aluminum and steel alloys used in car manufacture or manufacture of the ESV prototype vehicles.

Table D3 shows a comparison of materials choices for various parts of the prototype vehicles built in the NHTSA program. As may be seen, there was a fair diversity of choice in materials, particularly among nonstructural parts; e.g., fenders. In their report, GM stated that they used steel in the rear wheel wells only because of difficulty in

TABLE 12

ALLOYS USED IN VEHICLE CONSTRUCTION[2,5,6,7,8,9,10]

Alloy	Yield Strength (KPsi)	Ultimate Strength (KPsi)	Elongation %	Where Used
1010 Steel	32	44	42	Production auto
1008 Steel	35	50	30-40	bodies and frames
9Ni/4Co/.20C Steel	190	190	14	Fairchild ESV frame, bumper bars, roof support
Maraging Steel	275	280	6	Fairchild ESV rear structure
T-1 Steel	100	—	-	AMF ESV frame
HSLA Steel	80	—	-	GM ESV frame
2036-T4 Aluminum	27	49	24	Reynolds experimental aluminum car body
6061-T6 Aluminum	37	42	12	GM ESV bumper bar
7178-T6 Aluminum	78	88	10	Similar to 7175-T66 used on AMF ESV bumper bar

TABLE 33

MATERIAL CHOICES FOR ESV PROTOTYPES[5,6,7,8]

Manufacturer or Vehicle (Curb Weight, lb.)	Front Bumper Bars	Rear Bumper Bars	Bumper Facings	Frame	Roof Support Pillars	Doors	Front Fenders	Rear Wheel Wells	Rear Deck Trunk Lid	Roof	Floor Panels	Instrument Panel	Gas Tank	Radiator	Engine Block
Fairchild Industries ([illegible])	HSS Steel	HSS Steel	Steel Cap (Front) Plastic Foam (Front)	HSS Steel	HSS Steel	Aluminum + Steel	NS	Steel	NS	NS	Aluminum	NS	[illegible]	Copper	Cast Iron
AMF ([illegible])	Aluminum	Aluminum	NS	HSS Steel* HSS	HSS Steel*	Aluminum & Fiberglass	Fiberglass	Fiberglass	Fiberglass	Fiberglass	NS	NS	[illegible]	Aluminum	Cast Iron
GM ([illegible])	Aluminum	Aluminum	Urethane Foam	HSS Steel	HSS Steel	Aluminum	Aluminum	Steel	Aluminum	Aluminum	Steel	Aluminum	Steel**	Copper	Aluminum
Ford ([illegible])	HSS Steel	Aluminum	Urethane Foam	HSS Steel	HSS Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	[illegible]	Aluminum	Cast Iron

Notes: HSS = high strength alloy

NS = not specified in available reference

* AMF frame includes passenger compartment—column of same conventional design

** only fuel tank to fail during crash tests developing a deep draw die for aluminum sheet within the time limits of their program.[8] GM generally stressed use of aluminum in their car. Although the GM car was the lightest, some weight saving must be attributed to their deliberate choice not to design to the 10 mph-no damage front/rear collisions criterion.

One area where choice of material was unanimous was in the frame and roof support structure. All manufacturers designed using a high strength alloy steel. As pointed out in the discussion of bumper bars, there is no theoretical reason why an aluminum frame of equal strength and approximately equal weight could not be used. However, the overall bulk of the structural members, the increased cross sectional size, and greater difficulty in fabricating the large size pieces, probably mitigated against the choice of aluminum as opposed to the high strength alloy steels.

D.3 Conclusions

Present Federal Motor Vehicle Standards do not appear to limit the materials choices of manufacturers, where choice is possible. However, fiberglass bodies apparently require steel or aluminum substructure to meet crash worthiness standards, presently only applicable to doors and roofs.

Imposition of crash energy management standards, such as imposed during NHTSA's Experimental Safety Vehicle program, if ever implemented, will tend to increase car weights and create very strong incentive to minimize weight in nonstructural parts. These weight reduction incentives will arise from the need to minimize vehicle kinetic energy, since the weight and cost of the main structure and the energy absorption will rise in direct proportion to vehicle mass.* Structural parts which receive very high loads during collisions, such as frames, roof support pillars, and bumper bars, will very likely be made of the high strength alloy steels, since the weight saving available from use of aluminum in these applications appears to be fairly small.

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*This quite apart from fuel economy incentives.

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APPENDIX E

ENERGY CONSEQUENCES
by T. Jones

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ENERGY CONSEQUENCES

There are several energy consequences of the car compositions and weights described in Reference 7. The mix of primary and secondary materials has some effect. The directness of recycle of materials also has some effect. The overall weight, however, is the dominant factor of consequence to energy consumption in automobiles.

E.1 Direct vs. Total Service Energy

The distinction between direct energy and total service energy is a useful one to make because most of the changes in composition and weight most affect only the direct energy. Direct energy is that energy necessary to produce and run the transportation *machine*, the automobile. Total service energy is all the energy required to run the transportation *service* an automobile provides. This includes direct energy plus the energy used to run the industries of automotive sales, service, fueling, insurance, parking and highway construction.

Since material and weight questions affect the direct energy portion of the automotive transportation service, that will be considered first. Once the effects on the energy required to make and run the machine have been ascertained, any wider effects can be discussed.

E.2 Direct Energy

Direct energy can be divided into two categories: production and operating energy. Production energy is that which is embodied in a new car--all the BTU's necessary from raw materials to a finished machine. Direct operating energy is that energy which is embodied in the fuel and materials used during the service life of the car. Another distinction which will be discussed is the recoverable energy embodied in a car after its service life is finished.

E.2.1 Production Energy

Production energy has two components, the energy embodied in the material used and the energy used in fabricating and assembling parts into a finished machine.

Many varied estimates have been made as to the energy required to produce a pound of steel or aluminum. Some just include the process energy; some include that plus mining; some include mining, transportation and process energy and any entrained feed stock energy. A recent compilation of these estimates by D. K. Samples of Chrysler Corporation[1] is the basis for the estimates presented in Table E1. These estimates are an effort to include all direct energy required to produce a pound of material likely to be used in an automobile.

A pound of material is usually composed of some virgin primary material and some reused secondary material. The mix of primary and secondary materials changes the aggregate energy requirements. In low carbon steel for example, a primary pound requires 26,500 BTU. A secondary pound requires only 14,600 BTU, or 44% less. This percentage difference is expressed as a recycle energy factor. This factor is high for materials which require a large amount of energy for refining as opposed to final preparation, like aluminum, and low for materials that require a large amount of energy for final preparation, like cast iron. These two BTU figures are aggregated in the percentages shown to arrive at an average BTU/lb. for rubber, oil and plastic. The feedstock energy content is shown separately. At present the auto industry uses aluminum for mostly casting. Most of this aluminum comes from prompt scrap and thus requires only secondary BTU's. In future years, aluminum applications will require sheet aluminum, which requires more primary aluminum. Assuming that 2/3 of the difference between the aluminum now in a car (Reference 7, Table 12) and what is projected for composite cars in 1980 and 1990 (Reference 7, Table 14-19) will be primary aluminum, one arrives at the following mix of primary to secondary aluminum and the requisite aggregate BTU value/lb.

	1980			1990		
	% Primary	% Secondary	BTU/lb	% Primary	% Secondary	BTU/lb
Max. Aluminum	45.9	54.1	55,900	54.5	45.4	64,490
Max. Plastic	36.7	63.3	46,700	37.6	62.4	47,610
Best Estimate	29.5	70.5	39,500	44.5	55.5	54,500

The BTU values in Table E1 were used in conjunction with the car composition charts presented in Reference 7 to arrive at a total direct energy materials expense for the maximum aluminum, maximum plastic and best estimate compositions for each size class. This was done using primary material energy coefficients and also using the present mix of primary and secondary energy coefficients (except for the previously mentioned aluminum modification). The results are summarized in Table E2. When only primary materials are used (the figures in parentheses), the maximum aluminum car is most energy expensive, while the best estimate composition car is least expensive. The ranking changes with mix of primary and secondary materials. Then the maximum plastic option is least energy expensive followed by the maximum aluminum car, followed by the best estimate option. This shift in ranking is due to the extensive use of secondary aluminum, with its high energy recycle factor. In 1990, the maximum aluminum car again is the most energy expensive. The more extensive aluminum utilization requires aluminum sheet and alloys which cannot be formulated for secondary sources. Thus, more primary aluminum is used per car, and a higher materials energy cost results.

Materials are then fabricated into an automobile. The energy required for such fabrication is assumed to vary primarily with

TABLE [illegible]

DIRECT MATERIAL ENERGY [illegible]

Material	Primary Production BTU's/LB	Secondary Production BTU's/LB	Recycle Energy Factor¹	Aggregate Energy % Primary	% Secondary	Aggregate BTU/LB
Low Carbon Steel	35,500	14,800	.[illegible]	53.9	46.2	25,200
Alloy Steel²	39,000	15,072	.[illegible]	53.9³	46.2³	32,300
Cast Iron	[illegible]	10,300	.742	—⁴	100.0⁴	10,300
Aluminum	110,000	10,000	.[illegible]	—	100	73,000
Copper, Brass	65,700	13,600	.792	60	40	44,000
Lead	25,000	22,000	—	50	50	27,000
Other Metal	72,000⁵	—	—	—	—	—
Zinc	45,500	45,500	—	—	—	45,500
Rubber	3[illegible],000	—	—	100	—	36,000
Glass	73,000	—	—	100	—	73,000
Plastic (Process)	25,000	—	—	100	—	
Plastic (Feedstock)	20,000	—	—	100	—	45,000
Other Non-Metal	7,000	—	—	100	—	7,000
Oil	130,000 BTU/gal	—	—	—	—	130,000 BTU/gal

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[1] $\frac{\text{Primary Energy} - \text{Secondary Energy}}{\text{Primary Energy}}$

[2] Includes stainless.

[3] Assume same primary to secondary fuel ratio as low carbon steel.

[4] The most aluminum used in the auto industry is casting aluminum made from secondary aluminum. The overall aluminum industry average is 40% primary and 50% secondary or 75,000 BTU/lb. Future aluminum application to autos is expected to involve more sheet (primarily aluminum) than at present (see text).

[5] Estimate.

Source: Reference 1, Table 1.

TABLE E7
DIRECT MATERIALS ENERGY EXPENSE PER CAR
(million BTU's)

Composition	1980 Size Class A	B	C	Composite
Maximum Aluminum	92.17 (127.76)*	64.50 (86.81)	49.05 (69.41)	69.03 (94.36)
Maximum Plastic	79.10 (112.60)	60.43 (78.16)	47.27 (61.66)	63.96 (83.04)
Best Estimate	86.29 (115.3)	66.09 (86.30)	49.36 (63.52)	69.14 (86.83)

1990 Maximum Aluminum	A	B	C	Composite
Maximum Aluminum	11.50	70.96	53.64	74.17
Maximum Plastic	86.60	59.01	42.97	61.47
Best Estimate	89.86	63.10	40.11	66.24

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*BTU's if only primary materials were used.

the weight of material fabricated. By using a Chrysler estimate,[9] a figure of 6,880 BTU/lb. of automobile was obtained. This figure was used to derive the fabrication energy expense for each option shown in Table E3. The energy intensiveness of fabrication is assumed to remain relatively constant through time. On the one hand, lower pressing for aluminum may result in lower energy consumption. On the other hand, high energy dissipation makes welding more energy expensive, so a constant BTU/lb is assumed.

E.2.2 Direct Operating Energy

Having computed the two components of direct production energy, the direct operating energy is next. The largest component of this segment (and the largest single component in direct or total service energy) is fuel consumed. Other components are lubricating oil, tires and other replacement parts.

Fuel use scales most directly with the weight of the car. This is shown on Figure E1.[3] Fuel economy at a given weight can be improved by technological measures and mostly by decreasing acceleration performance. For this study only fuel consumption changes due to weight are considered.

The fuel economy, gallons of gasoline and BTU for each option class are shown in Table E4. A 100,000 mile lifetime is assumed for these figures. The direct energy cost of refining gasoline is included in the 125,000 BTU/gallon figure.

Other direct operating energy expenses include lubrication oil, tires and spare parts. Oil use and consumption are shown in Table E5. This table assumes a lifetime average of one oil change every 3,000 miles and one quart between changes. The oil use rates

TABLE E3

FABRICATION ENERGY*

(million BTU)

Size	1980 MA	1980 MB	1980 BE	1990 MA	1990 MB	1990 BE
A	25.20	26.00	26.60	21.46	22.44	23.89
B	17.07	17.93	18.41	14.74	15.24	16.46
C	13.06	13.64	13.94	11.13	11.61	12.44
Comp.	18.08	12.44	19.38	15.58	16.19	17.36

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*At 6.005 X 10^3 BTU/lb. of auto

Based on Reference 2.

FIGURE E1
TECHNOLOGICAL POTENTIAL
FOR FUEL ECONOMY 1975-1985

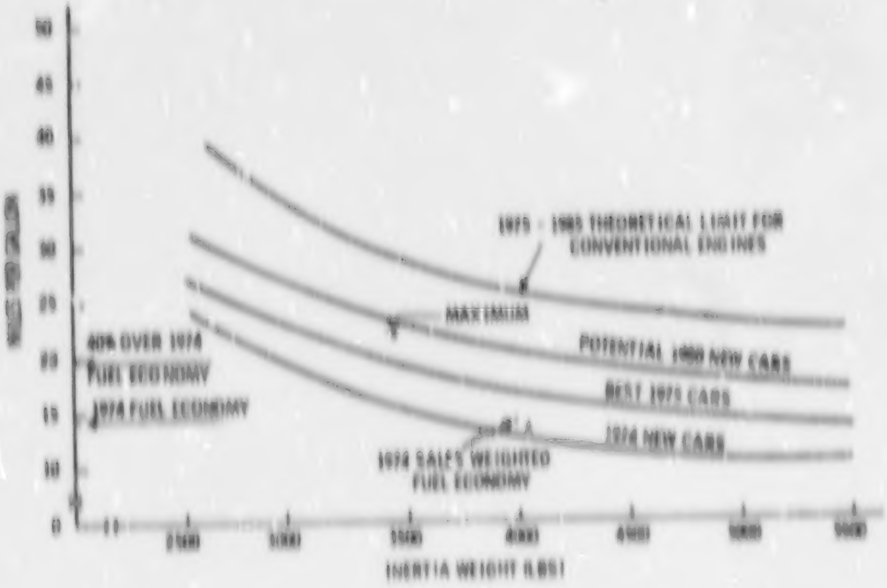

TABLE 24

FUEL ENERGY CONSUMPTION

Size	1980				1990			
	Weight	Miles Per Gallon	Gallons/ 100,000 Miles	Million BTU (at 125,000 BTU/Gallon)	Weight	Miles Per Gallon	Gallons/ 100,000 Miles	Million BTU (at 125,000 BTU/Gallon)
MAXIMUM ALUMINUM								
A	3,611	16.5	6,060	757.5	3,117	18.0	5,555	693.7
B	2,440	22.8	4,386	548.1	2,141	25.0	4,000	500.0
C	1,897	26.1	3,831	478.9	1,610	29.0	3,448	431.0
Composite	2,626	21.0	4,761	595.1	2,264	24.3	4,115	514.3
MAXIMUM PLASTIC								
A	3,777	15.0	6,666	832.5	3,260	17.5	5,714	714.4
B	2,605	21.7	4,608	576.0	2,213	24.3	4,115	514.4
C	1,982	25.8	3,875	484.4	1,687	28.5	3,508	438.5
Composite	2,750	20.0	5,000	625.0	2,352	22.8	4,386	548.3
BEST ESTIMATE								
A	3,864	14.5	6,896	862.0	3,470	16.0	6,250	781.2
B	2,676	21.0	4,761	595.0	2,391	22.8	4,386	548.1
C	2,025	25.2	3,968	496.0	1,807	26.2	3,816	477.0
Composite	2,816	19.2	5,208	651.0	2,522	21.8	4,587	573.3

TABLE 15[1]

OIL USE AND CONSUMPTION

Class	1980					1990				
				Recoverable[3]					Recoverable[3]	
	Qts/Chg	Qts	$BTU\times10^{6}$(2)	Qts	$BTU\times10^{6}$	Qts/Chg	Qts	$BTU\times10^{6}$(2)	Qts	$BTU\times10^{6}$
A	5 + 1	198	6.43	158.0	5.14	4 + 1	180	5.89	144.0	4.71
B	4.5 + 1	180	5.89	144.0	4.71	4.25 + 1	173	5.62	138.4	4.50
C	4 + 1	165	5.35	132.0	4.28	44.5 + 1	165	5.35	132.0	4.28

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[1] Based on 100,000 miles, one change/3000 miles and one quart between oil changes.

[2] BTU at 136,000 BTU/gallon.

[3] Recoverable based on 20% burned in use.

scale with car class and engine size.

Tires are most of the weight of new car rubber and some other rubber is included in "other non-ferrous." Rubber use also scales with car size. Assuming three complete tire changes, one of which is a retread,[8] one arrives at two times a new car's rubber worth of new direct energy expense for tires.

Replacement parts have a direct energy expense associated with them also. For a mid-sized Class B car, assume the following items are replaced:

- 3 mufflers at 33 lb. each = 100 lb. steel
- 1 body panel, 1 water pump, 1 oil pump, 1 fuel pump together at 100 lb. steel, 45 lb. aluminum, 5 lb. copper
- 2 batteries at 35 lb. each = 70 lb. lead

Assume 1/2 of these replacement accessories are rebuilt parts with little or no new embodied energy.
The totals become:

Material	-Energy Expense BTU/lb.	Total BTU
150 lb steel	21,000	3,150,000
22.5 lb alum.	10,000	225,000
2.5 lb cu	44,800	112,000
70 lb Pb	22,000	1,540,000
		5,027,000

This estimation is assumed to be 4.75 million BTU for a smaller Class C car and 5.25 million BTU for a Class A car. The replacement part energies complete the operating component of direct energy.

Both production and operating direct energies are summed in Table E6 to come up with the total direct energy for each composition and size option. One can see that the production component is slightly over one tenth (12-13%) of total direct energy consumed. Fuel consumption is the largest single direct energy use. Both production and operating energies depend heavily on the weight of the car. This can be seen by comparing the 1980 consumption with a 1990 consumption for a lighter car of the same class. The composite best estimate car goes from 760 million BTU to 676 million BTU, an 11% decrease for a 10% decrease in weight.

Because fuel use is dependent upon weight, the use of much more high energy lightweight material (plastic or aluminum) would appear to be justified over the life of the car. Using the 1980 to 1990 best estimate composite car as an example, a 294 lb weight decrease yields a 78 million BTU fuel savings over the life of the car. 10% of that figure (in keeping with the normal fabrication to fuel energy ratio) represents 780 lbs. of secondary aluminum, about 200 lbs. of plastic and about 78 lbs. of primary aluminum. In a study by C. Norman Cochran,[6] an "energy return factor" was computed for aluminum. This factor is the energy saved by saving weight with aluminum divided by the additional energy required to make aluminum and the arrival at an energy return factor of 2.7 for each lb. of steel replaced with aluminum[*] on an equal metal volume basis. Thus, some energy expensive fabrication material can be justified from a fuel energy savings point of view.

Completing the energy life cycle of an automobile, the maximum energy recoverable from materials (rubber and plastic) and oil are also shown in Table E6. These figures were computed assuming a 20% loss of materials and oil, recoverable energies of 10,000 total lb. of rubber, 18,000 BTU/lb. plastic, and 130,000 BTU/gal of oil. The maximum plastics

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[*] This aluminum was a total industry mix of primary and secondary at 76,600 BTU/lb.

TABLE 55

DIRECT AUTOMOBILE ENERGY CONSUMPTION

(million BTU's)

Year	Size	Option*	Production			Operating					Total	[illegible]
			Materials	Fabrication	Subtotal	Fuel	Oil	Tires	Parts	Subtotal		[illegible]
1980	A	M.A.	92.77	25.20	117.97	757.50				783.06	901.03	14.52
		M.P.	78.70	26.00	104.70	832.50	6.43	13.88	5.25	857.63	965.73	15.22
		B.E.	86.29	26.60	112.89	862.00				887.56	1000.45	14.98
	B	M.A.	64.50	17.07	81.57	540.73				568.57	650.08	11.75
		M.P.	60.43	17.93	78.36	576.00	5.80	9.52	5.00	596.47	674.77	12.56
		B.E.	66.09	18.4	84.49	596.00				621.47	689.98	11.55
	C	M.A.	49.65	13.26	62.91	479.80				497.52	560.43	9.61
		M.P.	47.27	13.64	60.91	494.45	5.35	8.62	4.75	513.12	574.03	10.06
		B.E.	49.36	13.94	63.30	496.00				506.70	569.45	9.86
	Comp.	M.A.	68.02	18.08	86.17	595.70				616.55	702.66	11.67
		M.P.	62.95	18.44	82.39	625.00	5.89	10.56	5.00	646.45	728.84	12.21
		B.E.	69.74	19.38	88.52	651.00				672.45	760.97	12.03
1990	A	M.A.	141.50	21.96	121.96	693.70				716.50	838.46	13.05
		M.P.	85.40	22.44	107.84	714.40	5.89	11.61	5.25	737.20	845.04	13.93
		B.E.	89.96	23.89	113.75	761.20				784.00	897.75	14.30
	B	M.A.	71.96	14.74	85.70	500.00				520.00	605.70	10.90
		M.P.	58.87	15.28	74.15	514.40	5.62	9.38	5.00	534.40	608.45	10.58
		B.E.	62.78	16.46	79.44	548.70				568.70	647.74	11.85
	C	M.A.	53.04	11.73	64.77	437.44				450.57	515.28	9.19
		M.P.	42.97	11.61	54.58	438.50	5.22	7.46	4.75	456.22	510.57	11.50
		B.E.	48.11	12.44	60.55	477.00				494.53	555.08	9.88
	Comp.	M.A.	74.17	15.58	89.75	514.30				534.36	624.11	11.77
		M.P.	61.47	16.19	77.66	548.52	5.52	9.44	5.00	568.56	646.22	14.54
		B.E.	66.24	17.36	83.60	573.37				593.36	676.92	12.03

*M.A. = Maximum Aluminum
M.P. = Maximum Plastics
B.E. = Best Estimate

car is the highest in every case because of its larger feedstock energy. The total for a best estimate composite car is 1203 million BTU's in 1980 and 1990. This is 1.5 and 1.7% of the total direct energy for those years. Twelve million BTU/car is a significant amount of energy.

Completing the energy life cycle of the materials in an automobile, one can consider the overall energy consumed by a pound of primary material throughout its recyclable life. There are losses in all recycling efforts which reduce the recyclable quantity. Thus, for example, 1 lb. of primary yields .8 lb. secondary yields .64 lb. tertiary... Assuming five complete recycles with a 20% loss each time, we are concerned with 1 unit of primary material energy and (.80 + .64 + .57 + .40 =) 2.4 times the required secondary energy. We have the following energy values.

	Primary Energy Expense	+	Secondary Energy Expense	=	Total Energy Expenses	Total Energy Expense / Total Useful Pounds
	1 X Primary	+	2.4 X Secondary	=	Total	Total ÷ 3.4 useful lb.
teel	1 X 26,500	+	2.4 X 14,600	=	61,540	18,000 BTU/useful lb.
Cast Iron	1 X 12,000	+	2.4 X 10,3000	=	36,700	10,700 BTU/useful lb.
Aluminum	1 X 110,000	+	2.4 X 10,000	=	134,000	39,400 BTU/useful lb.

One can see that for the same number of recycles, cast iron is least energy intensive, and aluminum is most. This would indicate that materials with high primary energies must have a larger number of recycles to be on energy parity with materials requiring less primary input. Aluminum would seem to have that property, while any extensive recycle of plastics is still a question.

In summary, from a direct energy standpoint, weight is the primary determining factor for total direct energy consumed. It affects both material and fuel energy requirements. Material energy effects are limited to less than 10% of the total energy consumed. Embodied

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*Over five cycles, 3.4 lbs. of material are used.

materials show a range of 10% depending on materials composition, or 1% of the total direct energy. The mix of primary and secondary materials can affect the whole embodied energy fraction. Comparing a primary and secondary mix with only primary, a 20% savings in embodied energy has already been achieved. There is probably a limited potential for another 2-5% if more secondary material were used, but this potential is limited by functional requirements and the fact that secondary iron, steel and aluminum are already widely used.

E.3 Total Service Energy

Total service energy (of which direct energy is a subset) is shown in Table E7. On a fuel basis, 9,821 of the 16,100 BTU shown in Table E7 are for fuel use in 1970 as versus 6,510 BTU/mile in 1980. If all ancillary industries scaled down by the same amount as fuel, then one would arrive at a total service BTU/mile of 10,671. This, however, is unlikely. Assuming only the fuel difference of 3,311 BTU/mile one arrives at 14,000 BTU/mile (or a total service mileage of 8.9 miles/gallon). Reductions in materials and fabrication energy would bring the energy cost of the auto to 13,900 BTU/mile, assuming the same energy level for all ancillary service industries. Of this, 7,800 (57%) BTU/mile are direct energy and 6,100 (43%) BTU/mile are indirect energy costs.

E.4 Findings

The energy consequences of plastics and aluminum rest primarily in their ability to cut the weight of the car. The mix of primary and secondary materials can affect the energy necessary for producing the auto to a limited degree. Using more lightweight high energy materials can be justified on a fuel savings basis. High primary energy materials must be recycled more times than low primary energy materials to reach the same energy expense per unit of functional material over the lifetime of

TABLE E7

TOTAL ENERGY REQUIREMENTS FOR AUTOMOBILES IN THE UNITED STATES

Note: All energy figures are in units of 10^{15} BTU

	1963	1970
Gasoline consumption	5.80	8.94
Gasoline refining and retail sales	1.28	2.07
Oil consumption, refining, retail sales	0.07	0.11
Automobile manufacturing	0.66	0.80
Automobile retail sales	0.17	0.21
Repairs, maintenance, parts	0.35	0.37
Parking, garaging	0.22	0.44
Tire manufacturing and retail sales	0.09	0.23
Insurance	0.19	0.31
Taxes (highway construction)	0.73	1.00
Total (10^{15}BTU)	9.56	14.48
Total United States energy consumption (10^{15} BTU)	44.57	67.44
Percent of total energy consumption devoted to automobiles	21%	21%
On a Mileage Basis:		
Total automobile mileage (10^9 miles)	590	901
Total energy required (BTU/mile)	16,200	16,100

F16

Source: Reference 7.

that material. The energy use in automotive service industries is not likely to change due to lighter materials and cars, so the ratio of direct energy to total service energy is likely to decrease as time goes on.

E.5 REFERENCES

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